ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

RETHINKING TECHNICAL BIOLOGY IN ARCHITECTURE

M.Sc. THESIS

Amar PASIC

Department of Architecture

Architectural Design Programme

OCTOBER 2014

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

MİMARLIK'TA TEKNİK BİYOLOJİ'Yİ YENİDEN DÜŞÜNMEK

YÜKSEK LİSANS TEZİ

Amar PASIC
(502101053)

Mimarlık Anabilim Dalı

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Tez Danışmanı: Yrd.Doç.Dr. Hülya ARI

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Amar Pasic, a **M.Sc.** student of ITU **Institute of Science and Technology** student ID **502101053** successfully defended the **thesis/dissertation** entitled "**RETHINKING TECHNICAL BIOLOGY IN ARCHITECTURE**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Asst. Prof. Dr. Hülya ARI** ....
İstanbul Technical University

Jury Members : **Prof. Dr. Belkıs ULUOĞLU** ....
İstanbul Technical University

Asst. Prof. Dr. Togan TONG ....
Yıldız Technical University

Date of Submission : 03 September 2014
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To my family,

FOREWORD

I would like to express my deepest thanks to my advisor Asst. Prof. Hülya Arı for her support and patience in this study. I would also like to thank my family and friends who have supported this study under all circumstances.

October 2014 Amar PASIC
(Architect)

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ABBREVIATIONS

CAO	**:** Computer Aided Optimization
EPA	**:** Environmental Protection Agency
FEA	**:** Finite Element Analysis
IPCC	**:** International Panel on Climate Change
SKO	**:** Soft Kill Option
TRIZ	**:** Theory of Inventive Problem Solving
UNFCCC	**:** United Nations Framework Convention on Climate Change

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RETHINKING TECHNICAL BIOLOGY IN ARCHITECTURE

SUMMARY

This study aims to present a conceptual deviation of biology in architectural transformation through modernization. It is presumed that during the transformation architecture has lost some of its abilities as one of the active participants in the nature and therefore built environments of urbanization process have caused a decline in environmental conditions.

Second chapter reviews the discipline and the makings of biomimetics under origins and development, academic research methods and products in various fields which biomimetics has been intersected with.

Third chapter investigates conversion of architecture throughout modernization. It will demonstrate attributed meanings in architecture. In order to fulfill the gap, various analogies have been used, speculated and practiced during and after international style in architecture, however, neither have captured the essence of true meaning of natural apprehension. Mechanical input and new materials have been essential components in negligence of environmental preferences. As architecture became increasingly independent in building, it has undertaken analogical approaches of which, some were representations of architecture in metaphors. Furthermore, it will provide information on environmental effects of modernization and will display acts and conventions as counter measures. It will demonstrate change in properties of materials and their effects on chemical levels.

Fourth chapter suggests that plausible approach of biomimetics could renovate and restructure architectural idea of environmentally appropriate through its biological input. Although it is possible to reinsert biological input through various techniques there is a problem of limited access of information for architects. For that reason the thesis will explore various approaches and products. It will also present examples that have been evaluated under three categories of; structure, process and material. These examples will provide core principles of biomimetics for architectural design.

Fifth chapter will present various discussions and argue on challenges of biomimetics' integration to architecture.

In concluding remarks, it is suggested that analogical approaches that do not feature scientifically correct biological ingredients have created problems particularly in terms of environmental adaptation. Architectural approaches that are scientific or epistemological will provide new and versatile qualities equal to the number of vast number of already existing systems in nature with the growth of information domain.

As a crucial step of integration, it is absolutely necessary that biomimetics goes under restructuring as a part of architectural education.

MİMARLIK'TA TEKNİK BİYOLOJİ'Yİ YENİDEN DÜŞÜNMEK

ÖZET

Mimarlık doğası gereği devingen bir olgudur. Süreç içerisinde pek çok disiplin ile ilişki kurmuştur. Çok disiplinli yapısı ile günümüz sorunlarına çözüm sunma potansiyeli içeren mimarlık ile ilişkilendirilebilecek bir diğer bilgi alanı olan biyolojinin özellikle biyomimesis kavramı üzerinden incelenmesi gerekliliğini ortaya çıkarmaktadır. Biyomimesis'in yapısı gereği; bilginin biyolojiden mimarlık ve mühendislik disiplinlerine aktarılması doğrusal olmayan bir süreç olması sebebiyle çeşitli sorunları da doğurmaktadır. Bilginin aktarılması konusunda bilimsel analojilerden faydalanmak önem kazanmaktadır.

Mimarlık tarihsel süreç içerisinde çevresinde yer alan biyolojik oluşumlara parallellik göstermiştir. Erken dönem medeniyetlerinde başlayan bu süreç içerisinde, doğada gözlemlenen olgular, kimi zaman insanüstü olarak nitelendirilirken; insanlar tarafından üretilen nesneler de bu fenomeolojinin yansıması okunabilmektedir. Analojik yaklaşım, insanüstü olarak kabul edilebilecek durumlar ile bu süreç içerisinde bağ kurulmasını sağlamıştır. Bu süreç teknolojinin insanın ihtiyaçlarını sağlaması konusunda baskınlık kazanması ile başka bir boyut kazanır. Kritik nokta olarak tarih boyunca doğadan doğrudan faydalanan toplulukların artık sanayi devriminin gözetimi altında tutulması ile doğanın nesnelliği insanüstü bir olgudan kolayca şekillendirilebilir bir nesne halini alır.

İlk mekanik girdilerin mimari tasarıma etkisi onu makineleşen analojik yaklaşımlara sevk ettiği gibi; mühendisliğin sunduğu olanaklar da mimarlığın çevresinden soyutlanmasına yol açacak bağımsızlığı getirir. İlerleyen aşamalarda bu bağımsızlık doğa açısından ağır bir bilançoya sahip olacağına bakılmaksızın yeni kavramsal arayışlarla birlikte çeşitli analojik yaklaşımları ortaya koyar. Bir aşamada analojik yaklaşımlar biyolojik olmaya da yönelir. Ancak bilimsel analojiden uzak bir tasarım dili olan mimarlığın ötesine geçemez. Sanayi devrimi öncesi toplumlardan kalma gelenekselci ve tüketimi sınırlandırılmış anlayışın oluşturduğu yerel mimari tavrın aksine, mimarlık biyolojinin ve ekolojinin tersine işleyerek günümüzde yüksek öneme sahip çevresel bozulmayı sağlayan araçlarından biri haline gelmiştir. Bu dönüşüm içerisinde mimari yaklaşım olarak bir kırılmanın ya da sapmanın varlığı altında yeni nesil mimarlıklarının içerebileceği bir kavram olarak biyomimesis'in incelenmesi önem kazanmaktadır.

Çeşitli kaynaklarda tariflenen Biyomimesis, doğada var olan oluşumların incelenmesi ve bu süreçte ortaya konulan tekniklerin taklidi olarak

değerlendirilebilir. Bir üretim tekniği olarak biyomimesis, kapsamı gereği mühendislik ve mimarlık dalları için de araştırma konusu olarak önem kazanır. Bu tez kapsamında, mimarlık pratiği içerisinde biyomimesis'in bilimsel yapısı, potansiyel üretim alanları ve muhtemel sorunlar incelenerek tartışılmaktadır.

Tezin yapısı dört bölümden oluşmaktadır.

Birinci bölüm biyomimesis disiplininin çıkış noktaları ve oluşumu esnasında önem kazanmış unsurları ortaya koymaktadır. Bu unsurlar ayrıca teknik biyoloji olarak tabir edilebilecek biyoloji'nin; matematikleştirilmesinden mühendislik alanlarında kullanımına dair süreci anlatmaktadır. Çoklu disiplinli yapısının diğer bilim dalları ile nasıl entegrasyan kurduğu gözlemlenmektedir. Bu bölümün sonunda disiplinler arasında teorik ya da uygulamalı bir dizi örnek incelenmektedir.

İkinci bölüm mimarlığın, çeşitli üretim şekilleri ve mekanik girdiler sayesinde modernleşme sonucu doğa içerisinde "bağımsız" bir hal alarak çevre kavramı açısından geçirdiği değişim gözlemlenmektedir. Bu bölüm modernleşme öncesi ve sonrası mimari anlayışların farklarını ortaya koymaktadır. Mimarlığın bu noktadan itibaren doğayı nasıl ele aldığı ve biyomimesis kavramının nasıl yanlış anlaşılabileceği üzerine geçmişte biyoloji'nin mimarideki ele alınış biçimleri gözlemlenecektir. Bu noktada bilimde de tanımlama amaçlı kullanılan analojik yaklaşım kavramsal açıdan incelenerek mimaride bilimsel olmayan yeni kavramların üretilmesi tartışılmaktadır. Mimarlığın, fonksiyonel ya da bilimsel olmayan kaygılar ile yürüttüğü analojik yaklaşımlardan dolayı çevreye doğrudan entegrasyonda zayıf kaldığı önerilmektedir. Bu bölümün sonunda biyolojik ve ekolojik kaygıları olmayan yapılaşmanın günümüzdeki etkileri gözlemlenmektedir.

Üçüncü bölümde biyomimesis disiplini içerisinde gözlemlenen tüm örneklerden yola çıkarak mimari açıdan kullanılabilecek üç temel sınıf önerilmektedir. Birinci sınıf strüktürel yaklaşımdır. Bu sınıf geçmişten günümüze genel yapı statiği prensipleri ile ele alınan büyük ölçekli yapısal tasarımlardan küçük ölçekli - biyolojide temel prensiplerden biri olan –yapısal eksiltme yöntemine dönüşmektedir. İkinci sınıf süreci konu almaktadır. Yapı, biyolojide önemli bir yere sahip adaptasyon sorununa çözüm olarak süreç içerisinde gelişen dinamiklere uyum sağlama potansiyeli içermelidir. Bu bağlamda mimari açıdan en temel sorunlardan biri olan iklim ve enerji konuları ele alınır. Üçüncü sınıf malzeme ölçeklidir. Bu sınıf bütünsel yapının en küçük parçasını ifade eder. Malzeme sınıfı günümüzde araştırma ve üretim yöntemlerinin gelişmesi ile yüksek önem kazanmıştır. Doğada gözlemlenen sistemlerinin çoğunda organizmalarda en temel unsurlardan biri olan pratik olma gereksinimi çok yönlü malzemelere dayandırılmaktadır. Malzemenin sağladığı katkının çok yönlü olması birçok etmenin bir bileşen sayesinde çözülmesi ile yapıya üst ölçeklerde hiyerarşik açıdan farklı nitelikler kazandırmaktadır.

Dördüncü ve son bölümde biyomimesis gibi disiplinlerarası bir bölümün mimari entegrasyon esnasında karşılaşabileceği sorunlar tartışılmaktadır. Bu sorunların başında, biyolojiden mimarlığa doğrudan değil, öncelikle biyolojiden mühendisliğe aktarılan bilginin daha sonra mühendislikten mimarlığa tekrar aktarılmasından dolayı oluşan üçüncü derece ilişkinin mimari tasarım fikrini geri plana itmesi gelmektedir. Bu durumda mimarlık biyoloji hakkında kendi fikirlerini yansıtma çabasında çeşitli analojik indirgemelere başvurmaktadır. Bir diğer sorun tasarım açısından doğru bilginin kullanılmasının biyolojik açıdan doğru kabul edilebilcek yöntemlere yol açmayacağıdır. Sonuç olarak, mimarlık açısından önemli bir yere sahip olduğu düşünülen biyomimesis’in mimarlığa entegrasyonu, kavranması ve tasarım girdisi olarak kullanılması için temel mimarlık eğitimine dahil edilmesi yüksek önem kazanmaktadır.

1. INTRODUCTION

Architecture is a progressive discipline that has collaborated with many other versatile and different fields during its evolution. This study focuses on the ability of architecture to collaborate with other disciplines. Disciplines regarded as mainstream are intercrossing each other to create new ones and with every step of overlapping fields, science grows with it as well. Architecture is able to grow by diversifying with every entry of a new theme or a subject. Fields such as material or computer engineering -originally used apart- have contributed to architecture's development in recent years. Multi-disciplinary collaboration is effective when a specific problem requires ad hoc solution, furthermore, this collaboration also triggers beginning of a new partnership in which exchanged working principles are aligned for future achievements.

Since modernization of production methods with the industrial revolution, notion of nature has been diversifying and even gradually undermined. Even though nature already possesses the required solutions architecture is in pursuit, evolution of civilized societies of industrial age brought alternative methods of engaging the surroundings. This new attitude with a rapid proliferation of technical capabilities showed negligence towards ecological and therefore biological systems. Change of physical, chemical and biological conditions in nature signify a deep alteration in human approach to nature. With the deterioration of environmental conditions an overall increased awareness of human impact on the natural environment emerges as a top priority concern. The study began by analyzing if architecture could have an active collaboration with biology. Heavily based on interconnection with other existing natural systems and networks of interrelations, Biomimetics is a combination of fields of biology and engineering that could provide assistance to architectural design idea in terms of new technologies and create a more correct response to environmental impact. As a subject of mixed identities, it can fulfill the gap between functional and imaginative analogies.

1.1 Purpose of Thesis

The purpose of this study is to take an in-depth look at biomimetics as a basis of science and engineering from the architectural point of view. Thesis investigates potential design production methods of biomimetics while analyzing and discussing probability of difficulties it may encounter. It is believed that conceptual differentiation of biological approach in architecture due to introduction of modern approaches and technologies in early Twentieth century have a significant contribution to deterioration of environmental condition. It will underline principles of biomimetics discipline as a bridge for incorporation of modest, stand-alone mediator for architectural design purposes. Originally coined as “Technical Biology”, biomimetics or bionics, is a field on the rise in fields other than architecture. The topic of biomimetics is very broad and covers many disciplines, with applications and implications for numerous areas. Study will investigate why such an essential field that involves deep environmental connection has not technically become more of an integral part in architecture.

1.2 Methodology of Thesis

As a subject of interest, this thesis has begun investigating possibility of architectural intersection with biology which consequently led to field of biomimetics. Thesis explores biomimetics in order to find out in what way biology may exist in architectural practice. Structure of methodology consists of three mains steps: Firstly, it undertakes gathering of information from literature of multidisciplinary origins and by participating in courses of the Faculty of Molecular Biology and Genetics at ITU. Secondly, it investigates several architectural approaches concerning analogical influences relative to the subject, and thirdly, analysis of information under major categories selected according to fundamental characteristics relevant to the architectural design. Collected data is analyzed under the categories of structure, process and material. Findings will provide insight to biomimetics’ working procedure and will be crucial for integration of subject into architectural design. Finally, it is discussed which sort of problems biomimetics could confront in architecture and a plausible recommendation for resolution.

2. DISCIPLINE OF BIOMIMETICS

Biomimetics is made of *Bios* meaning life in Greek and *Mimetics* which means having a talent for imitation. Webster's Dictionary defined it as "the study of the formation, structure, or function of biologically produced substances and materials and biological mechanisms and processes especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones" (1974). There are several other similar words for Biomimetics such as Biomimicry and Bionics used in various disciplines. Bionics is mostly used in German literature while Biomimetics and Biomimicry are used in some European countries and United States albeit, biomimicry implies a narrower method of working towards sustainment.

Method of biomimetics provides an in-depth study and understanding of solutions and strategies that have evolved in various environmental conditions. As a concept it stands for united, compact and complete system. In some aspects it responds to transformation of energy with the lowest amount of waste while functioning. This approach comes from the beings and structures in nature that are seemingly primitive and fragile. However, when the conditions are taken into consideration they are extremely durable. Natural systems enhance the usage of local energy but cut down the complexity of the processes and lower the amount of energy consuming functions. In this sense biomimetics does not suggest consideration of being ecological but it preserves state of self-sufficiency as its normal. The Association of German Engineers defines it as "a scientific discipline that systematically deals with the technical execution and implementation of constructions, processes and developmental principles of biological systems". In essence diversity and volume of nature's capabilities provides a wide scope of research topics in biomimetics. Various engineering disciplines have been using its features while architecture has been limited to explore biomimetics. Berkebile and McLenan (2004) state that Biomimicry is often described as a tool to increase the sustainability of human designed products, materials, and the built environment. Biomimetics approach presents many features for new unexplored environments, furthermore it extends scope of architecture's domain into various probabilities.

2.1 Origins and Development

As the field of biology advanced and the phenomena were translated into other sciences an interest grew towards natural systems. Biology has diversified with an incredible rate during twentieth century transcending into specific fields such as evolutionary psychology, socio-biology and genetics. Blandino (1969) in his book "Theories on the nature of life" explains how biology changes from mechanistic biology where Cartesian aspect perceives organism as a machine into modern biology. Driesh (1924) sated that the material systems which we call living organisms are not mechanical systems. This aspect was influenced mostly by Lamarkian determinism and Casualism against Darwinian approaches. On the other hand study of cells and their behavior along with taxonomic ramification of characteristics was a crucial step which led to a deeper curiosity among scientists. Oparin and Haldane discussed on origins of life through processes of nonliving matters called abiogenesis. Scientists argued on how biology diversified and preserved its basic structure at the same time. Biology scaled down from forms to cells.

> Form is not, therefore, a consequence of the nature of vital matter. A protoplasm that is identical in its essence cannot give origin to so many different figures. It is not at all by the property of protoplasm that one can explain the morphology of animals and plants. (Bernard, 1865)

New shapes under the microscope such as group of blood cells and microbes changed attitude towards nature. Nicolas Rashevsky (1938) in his book *Mathematical Biophysics* suggested that biology had to be mathematized in order to become engineered. Biology as a field has to have a common language in order to be understandable and shared with other fields of engineering, thus becoming more of a technical biology. Observing some of biological phenomena, D'Arcy summarized some of the organic behaviors as 'growth under stresses'. Such a differentiated distribution process of fibers emerges through sensing the patterns of loading, or stresses constantly received by the natural organism (Mingallon, 2012). D'Arcy gave some examples from his observations on mathematics of shells explaining that a spiral is a curve which, starting from a point of origin, continually diminishes in curvature as it recedes from that point; or, in other words, whose radius of curvature continually increases (1942). According to D'Arcy morphology was studying process of formation. D'Arcy recounted Haeckel's bio-crystallization theory in radiolarians which later inspired architects such as Buckminster Fuller. Biology became an attractor for many disciplines other than architecture. During the formation of multidisciplinary works some scientists such as Neumann and Penrose, a physicist and a mathematician suggested a theory on self-reproducing machines although in the past mechanical point of view deemed it infeasible. Such experimentations pushed the limits of fields into each other resulting in transformation of knowledge which would create multidiscipline such as Biomimetics.

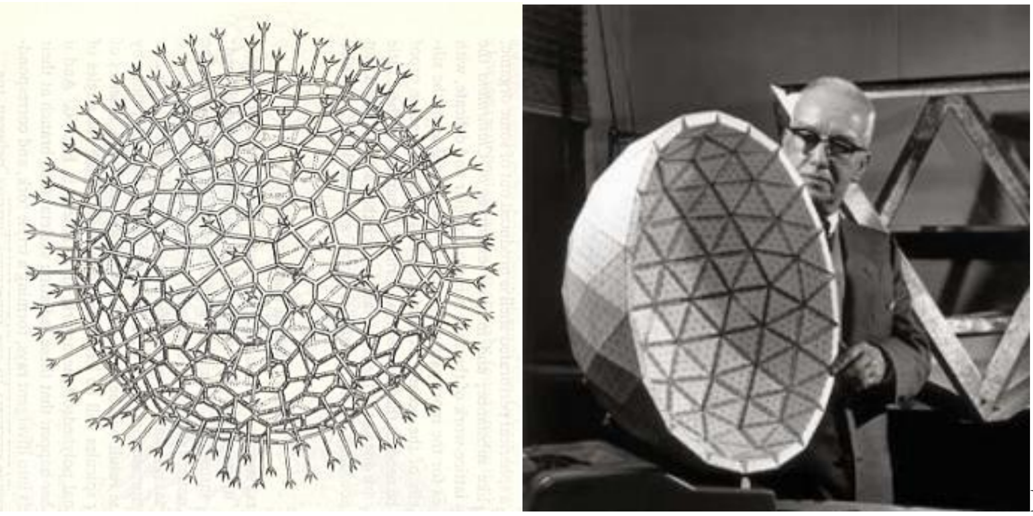

Figure 2.1: The shell of radiolarian aulastrum triceros (complete shell) was an inspiration for Fuller’s geodesic domes (Url-1, 2012)

As the humankind became more able in acquiring knowledge from nature, materials transformed into tools. Production methods rapidly evolved and the geometry became simpler and more controllable. Softness of materials in the environment turned into rigid constructions. Most of the production became industrialized. Despite the technological advances in Twentieth century, first examples of biomimetics were practiced in Renaissance era. One of the first pioneers in this field was Leonardo Da Vinci (1452-1519). Da Vinci's famous experiments on spread wings and their functional analysis studied weight ratio and muscle structure of flying birds. After Da Vinci's attempts Giovanni Alfonso Borelli (1608-1679) studied movement process of various animals. Sir George Cayley (1773-1857) studied selfstabilizing flight models and parachutes through the example of Tragopogon Pratensis.

In works such as Emmerich Zederbauer's *Die Harmonie im Weltall in der Natur und Kunst* (1917) and Ernst Mössel's *Vom Geheimnis der Form und der Urform des Seines*(1938) it is claimed that structural laws were considered crystalline because of microscopic findings like the structure of molecules. As it was accessible by scientist many observations showed what organic really was. Buckminster Fuller wrote about microscopic animal structures called *Radiolaria* comparing their structure to geodesic and spheroidal manmade structures. He also stated that *Radiolaria* was not symmetric and it was not as simple as it appeared. Organisms in nature started becoming inspirational on micro levels.

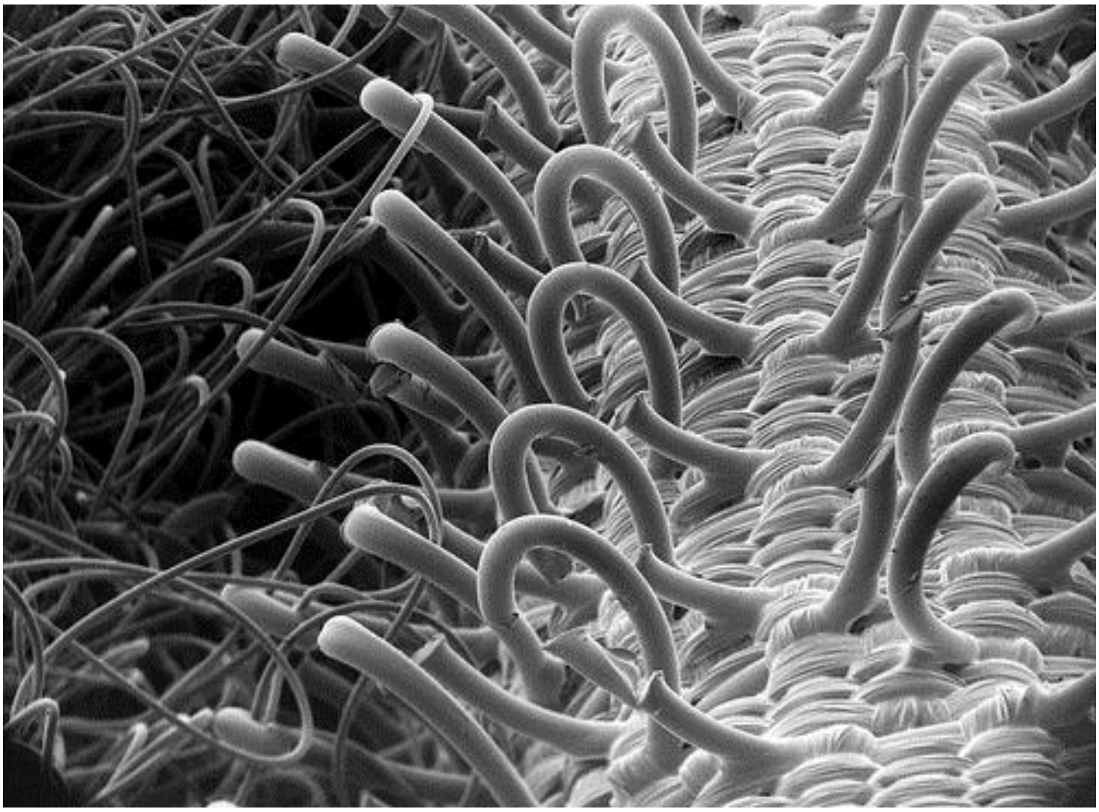

Figure 2.2: Velcro hook and loop under microscope (Url-2, 2012)

One of the first products based on biomimetics is Velcro's Hook and Loop Fastener. It was invented by Swiss electrical engineer George de Mestral in 1948. Design of Velcro was based on hooks of a plant called Burr which was observed under microscope. Hooks could connect with anything that had loop in it. In 1950, neurophysiologist Otto Schmitt officially coined the term Biomimetics. Schmitt Trigger was one of the first examples that simulated nervous system used for elimination of superimposed noise in electric circuits. This invention was an example of simulating signal processing taking place in the nervous system (Shimomura, 2010).

Biomimetics particularly has been studied by U.S. military engineers such as Lieutenant Jack E. Steele from Wright Patterson Air Force Base in Dayton, Ohio. In 1958 during a presentation Steele introduced term Bionics into military doctrines. According to Papanek (1971) until that point there hasn't been any written documentation in the field of Bionics. However some examples of bionics existed such as General Electric's heat-seeking missile based on the temperature sensing organs found in rattlesnakes called Sidewinder and radar and sonar systems which mimicked the echo-location device used by bats. Most of the experiments were military purpose and confidential therefore inaccessible.

2.2 Basic Principles

This part will present various approaches of researchers, inventors and institutions in the studies of biomimetics. As the field of biomimetics evaluates either a problem or a source that can anticipatorily become useful, researchers tend to provide their own methodologies. In recent years, production and applications have altered the theoretical framework since Juri Lebedew wrote first comprehensive work on Architekturbionik in 1960s. Lebedew emphasized that in nature, the principle of integration of function, form and structure is effective, and is adapted to the existence and interrelation with the environment. Lebedew grouped his studies under three major parts. First part is concerned with functions about methods of analysis and analogy of the natural and built environment, second part deals with construction principles of organic nature and third part investigates development of form and harmony. Most comprehensive work on biomimetics was published in 1990 by Werner Nachtigall who coined the term "Technical Biology" consisting of ten principles.

Table 2.1: Werner Nachtigall's principles for technical biology (1990)

1.	The concept of biological design can be understood in analogous relation to the concept of technological design

2.	The structural relation of technical biology and bionics is of image and reflection
3.	The organism forms a functional whole
4.	Biological design follows the principle of optimum integration
5.	The organism compensates for harmful overloading
6.	The overall size of an organism defines its stability
7.	An organism has environmental contact with the inorganic
8.	A form always meets multiple requirements
9.	The organism is in contact with other organisms
10.	The organism faces a permanent energy crisis

In his book Bionics: Theory and Examples for Engineers and Scientists, Nachtigall (1997) divided bionics into twelve subcategories:

Table 2.2: Subcategories of bionics (Nachtigall, 1997)

Structures bionics	Biological structural elements, materials and surfaces.
Device bionics	Development of usable overall constructions.
Structural bionics	Biological constructions, closely related to above structures and device bionics.
Anthropobionics	Issues of human/machine interaction, ergonomics.
Construction bionics	Light constructions occurring in nature, cable constructions, membranes and shells, transformable constructions, leaf overlays, use of surfaces, etc.
Climate bionics	Passive ventilation concepts, cooling and heating.
Sensory bionics	Detection and processing of physical and chemical stimulation, location and orientation within an environment.
Locomotion bionics	Walking, swimming and flying as primary forms of movement. Interaction with the surrounding medium.
Neurobionics	Data analysis and information processing.
Evolutionary bionics	Evolution techniques and evolution strategies, made useful for technology.
Process bionics	Photosynthesis, hydrogen technology, recycling.

Organizational bionics	Complex relationships of biological systems

However, all examples that can be found for bionics can be allocated to three broad, general subfields, which are according to Nachtigall further differentiated into subfields that respond firstly to Structural bionics concerned with nature's constructions, structures, materials, secondly, Procedural bionics concerned with nature's procedures or processes and thirdly Informational bionics dealing with principles of development, evolution and information transfer.

Biology started forming closer relationship with engineering fields in adaptation of multidisciplinary works. However, Vincent (2006) states that the organization of biology and engineering differ in approach. Organisms in biology develop through a process of evolution and natural selection which means that biology is largely descriptive and creates classifications, whereas engineering is prescriptive and generates rules and regularities which would end in decision-making. Engineering creates and manipulates through its own rules against understanding of soft transition in natural cycle. Observation and production in smallest scales by computer aided monitoring contributed to a great extent in development of biomimetic field. Observable sources from every scale in the nature diversified the method along the capability of the observer.

Use of biomimetics in architecture, in particular construction and climate bionics as Nachtigall puts it, responds largely to ongoing environmental and technological issues. As a field that studies the phenomena taking part in nature some researchers have attributed concepts that resemble to principles of sustainability. Domain of biomimetic research is based on cycle of energy and materials in the ecosystem. Eco-system as a constant cycle that is taking part in nature can be interpreted as an *Autopoiesis* where system reproduces itself while architecture is *Allopoiesis* where system produces something other than itself. For instance a pattern of some organic compounds is repeatedly found in the nature. Mingallon and Ramaswamy (2012) assert that cellulose, collagen, chitin and silk are the only four types of fibrous tissues found in natural constructions. Biology is capable of building all living organisms using only these four materials. This gives an idea on how nature can extract and diverse with simple compounds. Species evolve into structures and systems which can cooperate according to any condition where some species use environment as source for external shelter while others produce special tissues or exoskeleton shells out of simple compounds. Simplicity is crucial for optimal efficiency of body weight and usage of energy in production when whole cycle of organism's life is taken into consideration. By this principle living being becomes self-supporting and self-reliant while regulating harsh thermal changes, enduring various physical forces and preserving and harvesting energy. There are several different approaches in extraction of information and application through biomimetics. Gathering of information is based on specific research and researchers since there is no direct conversion of beings in nature into any practicable method. Methods tend to extract specific characteristics which can be applied into solutions.

2.2.1 Methods and Studies

The engineering principles of biological systems can be applied to the design of buildings as a process. It requires a commitment to evolutionary development, analysis of the material organization and behavior of individual species. Biological systems are made of weak materials to make strong structures and for that reason they differ to responses and properties of manmade structures. Plants, for example, are hierarchical structures, made of materials with underrated properties which can be changed by the plant in response to local or global stresses. High variety of parameters and responses exist, therefore all the researches are dependent on the specific subject of interest.

Organizations such as The Biomimicry Institute intercross multiple disciplines and research various probabilities in nature without any predetermined problem in order to create a taxonomic database. Institute was founded by biologist Janine Benyus in 2006. The Biomimicry Institute has developed functionally indexed database by the name of *AskNature* accessing scholarly articles relevant to biologically inspired design (Vattam, 2010). Biomimicry Institute (2011), describes working process of six phases following identification, interpretation, discovery, abstract, emulation and evaluation. Open-source database AskNature containing design and engineering functionalities of biological systems also works through these phases. Another similar approach has been proposed by Design Intelligence Laboratory. Methods work as problem-driven and solution-based. Two processes involve definition of biological solution, extraction of the biological principle and application of the biological principle (Helms, 2009). Problem-driven approach starts with the definition of problem than reframes and searches for biological solutions. After defining biological solution principles are extracted and applied. On the contrary solution-based approach identifies a biological solution, defines biological solution, extracts the biological principle, reframes solution and assumes a solution to a possible problem.

Yoseph Bar-Cohen (2006) in his work called *Biomimetics: Biologically Inspired Technologies,* points out that "approaching nature in engineering terms needs to sort biological capabilities along technical categories using a top-down structure or vice versa". Similar to principles of Design Intelligence Laboratory, Cohen proposes a *top down approac*h which is based on foregoing basic research studies to find possible natural models or concepts which are then used to elaborate a specific technical solution. As an opposite, *bottom up approach* starts by a definite technical problem and produce solutions from nature for an analogous problem.

Table 2.3: Characteristic similarities of biology and engineering systems (Cohen, 2006)

Biology	**Engineering**	**Biomimetics**
Body	System	Systems with multifunctional materials
Skeleton	Structure	Support structures
Brain	Computer	Emulation of brain
Nervous System	Electric systems	Based on characteristics
Intelligence	AI	Various
Senses	Sensors	Biosensors
Muscles	Actuators	Electro-active polymers
Electrochemical PowerGeneration	Rechargeable Batteries	Biological materials
DNA	Computer Code	Under development

Biomimetics research has also been conducted by TRIZ "Teorija Reshenija Izobretatel'skih Zadach" meaning Theory of Inventive Problem Solving. TRIZ was founded by Genrikh Altshuller (1946) "to produce a theory which defines generalizable patterns in the nature of inventive solutions and the distinguishing characteristics of the problems that these inventions have overcome". Method starts with definition of the problem and selection of properties and functions. Conflicts and contradictions are revealed and linked with TRIZ matrix where solutions are compared. TRIZ expands concept through categorical division of functions for chosen parameters to systematically solve identified problems. Based on TRIZ method research technology manipulates energy while biology uses structure and information from the nature. TRIZ reckons that if problems from distinct technological areas result in matching models, they must have similar solution patterns (Vincent, 2006).

In contrast to establishing a generalizable database and matrix based function solving, Maibritt Pedersen Zari (2007) proposed to categorize biomimetics into three different levels; Organism, Behavior, and Ecosystem. First level refers to mimicking of organisms such as plants, insects and animals. Second level mimics how an organism behaves and third level is the mimicking of whole ecosystems and the common principles (Zari, 2007). All three categories are divided into five sub categories as form, material, construction, process, function. Zari defines sub categories in the table below:

Table 2.4: A framework for the application of biomimicry by Pedersen Zari (2007)

Organism Level	Form	Building looks like a termite
	Material	A material that mimics termite exoskeleton
	Construction	Building made by the same way as termite
	Process	Building works the same way as termite
	Function	Building recycles waste and creates a surplus material
Behavior Level	Form	Building looks like it was made by termite
	Material	Built from same materials as termite built mounds
	Construction	Building made by the same way as termite
	Process	Building mimics how termites would work
	Function	Building works the same way as termite
	Form	Building looks like an ecosystem

Ecosystem Level	Material	Building made by the same natural way as termite
	Construction	Building assembled the way as termite
	Process	Building works the same way as termite capturing energy and storing water
	Function	Building participates in various processes

As a result there is no singular aspect on how biomimetics can be approached. In order to understand how biomimetics works researchers have devised several approaches which vary on examined subjects or problems that are in need of solutions. Zari’s proposition on three categories of organism, behavior, ecosystem divided by five sub categories is simple, however, as other approaches point out there needs to be a database of information which can be blended into multidisciplinary languages. Cohen’s top down and bottom up proposition shares similarities with problem driven and solution driven approach of Design Intelligence Laboratory. There are overall similarities between independent research groups. In terms of architecture it is not easy to access and directly transfer the information into design.

2.2.2 Developments in Various Fields

According to Weinstock (2006) design of natural living systems is not produced by optimization and standardization but by redundancy and differentiation. Biomimetics is a self-organization because it is respondent to an active adaptive process. Cells, tissues undertake a change towards specializing form or function in order to gain performance capacities. Self-organization promotes system’s properties and functions under increased order to satisfy its needs. Fundamental element for such system is the energy. As a system than; metabolism encompasses the physical and biochemical processes that occur within a living organism which are necessary for the maintenance of life. The biological purpose of metabolism is the production and storing of usable energy (Cohen, 2006). One such product is Artificial Photosynthesis. Artificial photosynthesis replicates the process of photosynthesis, converting sunlight and carbon dioxide into carbohydrates and oxygen in order to pave the way for self-sufficient and zero-pollution buildings that are independent from centralized energy-grids. Light photosynthesis-capable membranes are a promising direction for further development. Others include the use of living organisms, such as algae and bacteria (Nachtigall, 2002). In regard to artificial production of natural organisms, funded by the European Commission of 14 European and US universities and businesses, Programmable Artificial Cell Evolution (PACE) is an integrated program which is about development of artificial cells and methods to program their chemical functions for self-assembling purposes.

Virtual level of biomimetics includes computer simulations that are critical development tool for testing the behavior of simulated system and modification without the high cost of manufacturing. The development of computers and analytical tools, including numerical and logical models, has made possible a very powerful simulated representation activity. Such tools are used to investigate the performance of complex systems, and address such parameters as thermal, aerodynamic, mechanics, material behavior, and real-world factors (Cohen, 2006). Finite element analysis (FEA) is a well-known technique for the analysis of manufactured engineering structures. Numerical analysis technique is used for obtaining solutions to the differential equations that are used to describe a wide variety of physical problems.

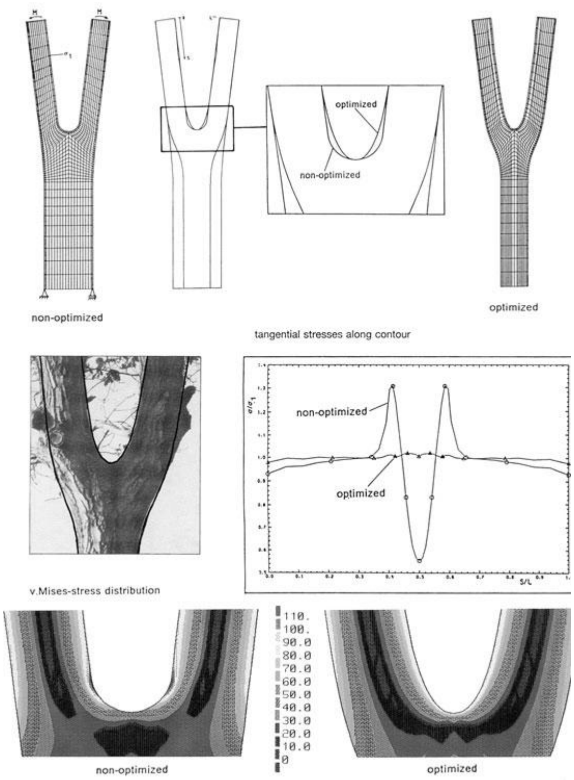

Figure 2.3: Comparison of stress in an optimized and a non-optimized fork by Mattheck (2007)

A software for calculation and reduction and optimization of the structure was proposed by Mattheck (1989) in terms of stress relief observed in adaptive growth of trees. A method called Softkill (SKO) suggests reduction of unnecessary structure as much as possible and optimizes topology of constructive parts while minimizing the amount of material. Softkill has been used by automotive manufacturers such as Daimler and Opel. There are several other software programs such as Topostruct in which it uses similar principles for material reductions. Furthermore, case studies on bamboos have been investigated by Michael Weinstock in Emtech Masters Program at the Architectural Association where bamboo`s cross-section has been examined. Cellular organization of bamboo’s fibres responds to stress loadings.

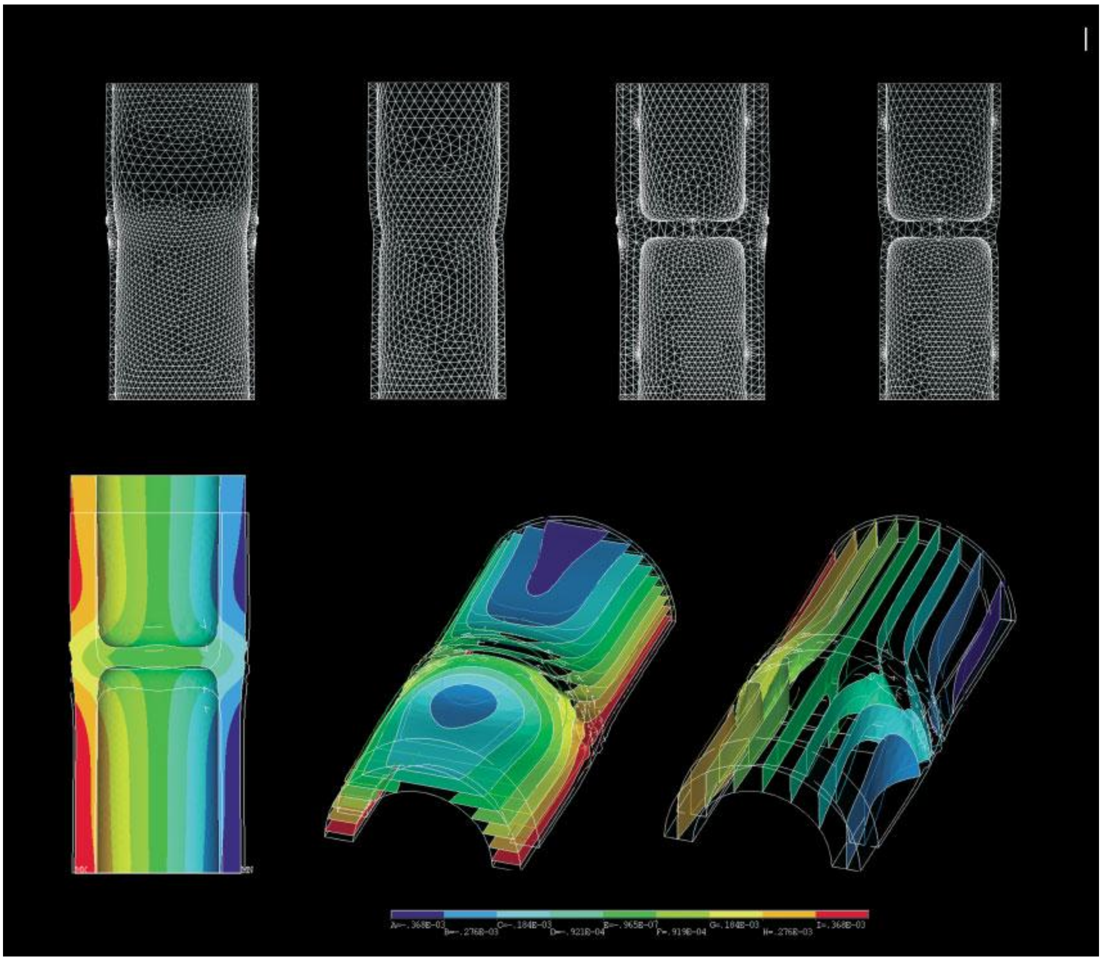

Figure 2.4: Algorithmically generated isosurfaces showing deformation of bamboo under tension loading by Weinstock (2006)

On materials level new composites with increasingly complex internal structures have been developed based on biological models. Strong transparent or translucent films can be produced with a water-repellent and self-cleaning surface for facade systems from mimicking self-organizing behavior and complex functions of natural polymers. There are materials with five times higher high tensile strength while being lighter than steel such as Kevlar which has been adopted for lightweight cables and ropes in many marine and naval applications. Due to its high impact resistance it is being used in military and civil aircraft. Kevlar has not been used widely in architectural construction. Kevlar is produced, in part, by manipulation of the liquid-crystalline in polymers. Spiders use the low viscosity in the liquid crystalline regime for the spinning of their silk. There are also industrial and economic techniques for production of foams in metals, ceramics and glass. Foamed cellular materials gain extraordinary properties by cellular solids, analogous properties to those of biological materials while manufactured from inorganic materials (Cohen, 2006).

> The production processes for metal foams and cellular ceramics have been developed for the simultaneous optimization of stiffness and permeability, strength and low overall weight. This is the logic of biomimetics, abstracting principles from the way in which biological processes develop a natural material system, applying analogous methods in an industrial context, and using stronger materials to manufacture a material that has no natural analogue (Cohen, 2006).

A Los Alamos National Laboratory sponsored project called Protocell Assembly, seek to assemble a minimal self-replicating molecular machine where nano-systems can perform useful tasks. Several universities are conducting research into membrane materials that incorporate biological molecules capable of selective recognition of a specific signal in such a manner that the membrane will respond by changing its porosity which will enable other molecules to permeate the membrane (Cohen, 2006). This development could contribute to architecture with smart biological membranes that can interact with their environment based on self-assembling biological structures and polymers. There are also drag resistant materials based on shark's skin. The tiny scales covering the skin of fast swimming sharks, known as dermal denticles (skin teeth), are shaped like small riblets and aligned in the direction of fluid flow. Shark skin inspired riblets have been shown to provide a significant drag reduction up to 9.9% (Bechert, 1997).

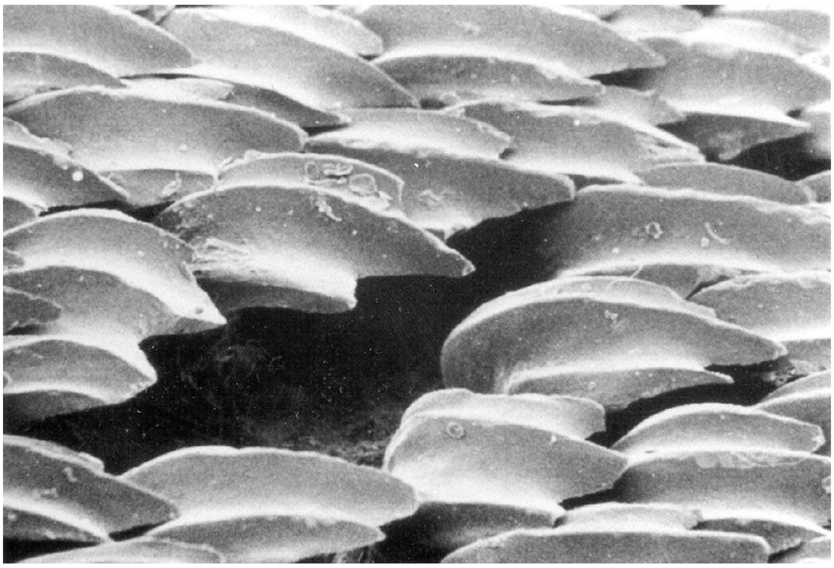

Figure 2.5: Dermal denticles shaped as riblet on micro scale (Url-3, 2013)

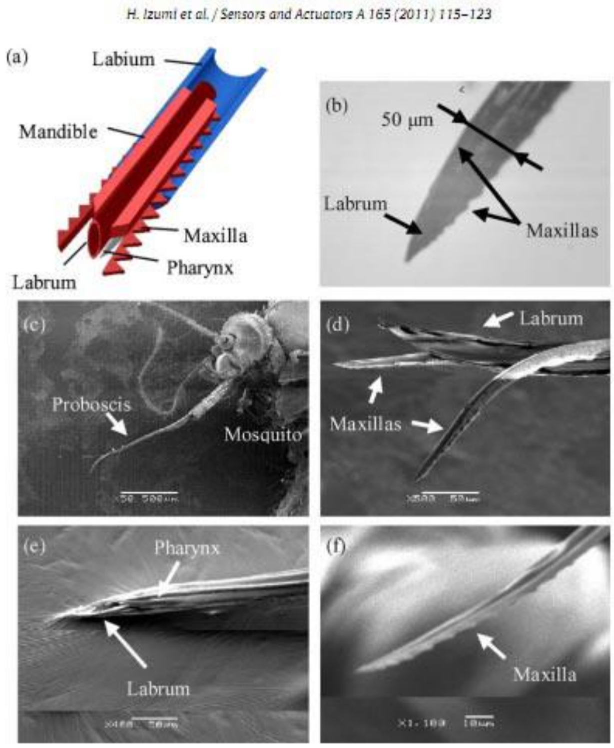

Figure 2.6: Realistic imitation of mosquito’s proboscis (Izumi, 2010)

Moreover, researchers in Japan have been studying mosquitos’ proboscis as a painless needle for medical applications. For the mosquito, the effective transportation of materials relies on an external source, and is effective because of the specific form of the proboscis and the specific process that form enables (Izumi, 2010).

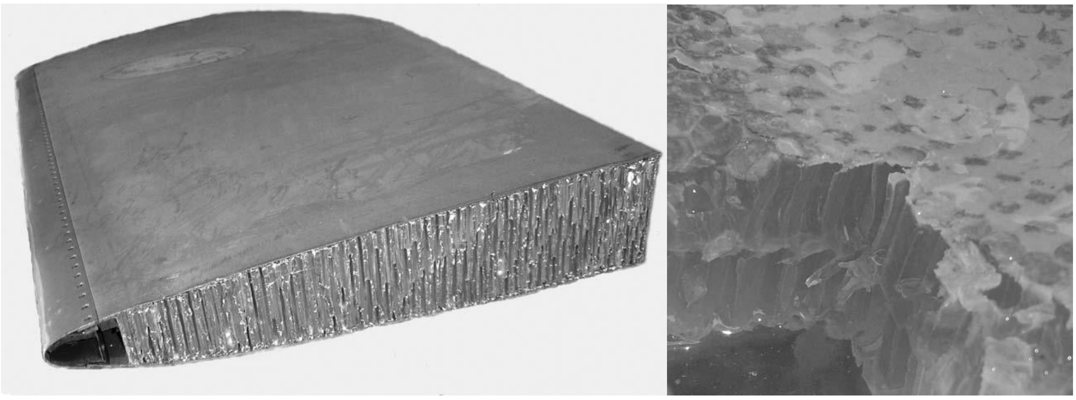

Figure 2.7: A cross-section of a honeycomb structure of aircraft control surfaces (left) and the honeycomb (right) (Url-4, 2012)

Honeycombs, used in many aircraft structures may not have been directly inspired by the honeycombs made by the bees (Gordon, 1976). However, it is still the same structure and the aircraft structure's name is the same as the product made by the bees. Biomimetics has been covered in the field of robotics. Robots can operate in hazardous environments which are deemed dangerous for humans. Robotics industry became interested in biomimetics with the introduction of lightweight microprocessors and powerful software tools including artificial intelligence techniques. Producing legged-robots based on biomimetic studies is increasingly becoming an objective for robotic developers.

2.3 Chapter Evaluation

Research and development of biomimetics is heavily invested in micro and nano scaled production. Highly technological production methods recently reactivated interest in biomimetics as it is now more possible to produce in extremely low scales. It possess high potential for future architectural applications which are already taking part in small quantities because of complex production methods. According to Bar-Cohen (2006) industry has a "top down" approach to biomimetics due to its commercial and functional value while researchers -as a "bottom up" approach- tend to explore a vast area of opportunities. Successful development of biomimetics depends on well-coordinated collaboration among groups that are seemingly split between specific interests. On the other hand, "efficiency" and "optimization" have differing meanings in biological structures, which feature complexity with redundancy. Biological systems respond and adapt to environmental dynamics therefore their responses are nonlinear and versatile. The definition of the biomimetics differs fundamentally by the sepcifications and points of interest for each research group, therefore it is remarkably ambiguous and easy to be misused. As a result, it is a complex field involving vast number of disciplines. The complexity in transfer of knowledge from biology into engineering and eventually to architecture indicates a difficult procedure.

3. CHANGING ARCHITECTURAL VIEW ON NATURE

This chapter presumes that architecture as a discipline has become estranged to nature. It is very important to explain the course of events that lead architecture towards efficient conduct of its both tangible and intangible values. This part will present process of changing look towards nature in parallel with shifting conditions. It will demonstrate concerns for environment and measures that are in connection with building industry. It will outline a chronological and technical progress of architecture's pursuit of nature through various analogical approaches.

3.1 Pre-industrial and Post-industrial Architectural Aspects

Gurenc (1990) states that the peasant world view holds that resources available to man are limited. Vernacular architecture can be expected to have been built according to the basic principle of 'limitedness'. Habits and concerns changed rapidly with transition to technology and machinery driven by energy during industrial age in which communities and cultures altered the means of engaging problems. Early modernism did not had the same attitude as present day architecture towards ecology. The notion of nature had a more romantic approach concerned about architectural aesthetics of the environment in which it was being built. Vernacular architecture which is delivered as sustainable by default is concerned with a local problem, local materials and local climate. As a model for environmental architecture vernacular can be observed under two aspects. An anti-industrial, pro-craft vernacular revival or as a source of valuable principles and tried and tested techniques of passive environmental design. Vernacular architecture comprises the dwellings and all other buildings of the people. Related to their environmental contexts and available resources, they are customarily owner- or community-built, utilizing traditional technologies. All forms of vernacular architecture are built to meet specific needs, accommodating the values, economies and ways of living of the cultures that produce them. Since the industrialization masses are moving and accumulating from agricultural sites to very dense urban areas in order to have an access for basic necessities leaving vernacular settlements in the past. Traditions of cultures and their intangible values have been slowly deactivated under the influence of newly forming modern world.

Contrary to those who lived in the cycle of nature, urban populations used nature as figures. Early movements on integration of nature in late nineteenth century architecture appeared in works such as Stile Floreale, Jugendstil and in the works of Antoni Gaudi who stated that “the architect of the future will build imitating Nature, for it is the most rational, long-lasting and economical of all methods.” Mostly figures or proportions of structures in nature were considered a design material. In 1900 Rene Binet designed Paris World Exhibition Entrance which was an example of zoomorphism.

Figure 3.1: Paris world exhibition center (Url-5, 2013)

In contrast, the enthusiasm brought by mechanical advantages architecture took a very decisive formation. All the details and efforts of vernacular architecture were rendered obsolete. Modern architecture with all the mechanical advantages at disposal became one global-international style which could be implemented to all cultures, climates and geographies. This is where architecture truly lost its touch with nature and procreated itself as a sovereign. This is also when architecture became dependent on external support. In this turn of events Le Corbusier (1984) summarized the approach by stating that; "every nation builds houses for its own climate. At this time of interpenetration of scientific techniques, I propose: one single building for all nations and climates".

Banham (1984) argues that the use of this new technology was not so straightforward and with the promise of improved environmental quality was "ruthlessly sacrificed for the geometrical machine aesthetic and the honest expression of everything". Mechanical systems became essential in mediating between human being and climate to compensate for the building's inadequacies of structure and orientation. The addition of computer controls from the 1970s onwards merely reinforced the commitment to the sealed environment (Hagan, 2012).

With the emergence of International Style, every manifestation could have been accepted out of enthusiasm for a change. Collins (1998) addresses that functional forms evolved by the leading modern architects were widely accepted, however it also evolved into a condition of misuse, and nothing could better serve the advancement of architecture than that examples of this should be publicly singled out. Ideals of modernism were described by Jencks (1996): "Modern architecture is the overpowering faith in industrial progression and its translation into the pure, while International Style or at least the Machine Aesthetics has the goal of transforming society both in its sensibility and social make-up". Presumably as reaction to industrialization Organic Architecture emerged even before major achievements in biology of mid Twentieth century therefore it did not contain real biological input. Correspondingly architectural movements afterwards tried to get involved with biology on some levels. Steadman (1979) explains that the term 'organic analogy' involves a metaphorical comparison of works of art with the phenomena of nature, and is concerned with aesthetic qualities rather than with strictly scientific parallels. Contrary to the damage of modernism, Architects of

Modern Movement such as Alvar Aalto, Wright and Le Corbusier insisted on connection with nature. Organic Architecture came to a public attention when Louis Sullivan proposed the idea of “Form follows Function”.

> All things in nature have a shape, that is to say, a form, an outward semblance, that tells us what they are, that distinguishes them from ourselves and from each other. Unfailingly in nature these shapes express the inner life, the native quality, of the animal, tree, bird, fish, that they present to us; they are so characteristic, so recognizable, that we say it is natural it should be so. (Sullivan, 1896)

Wright (1954) stated that “form follows function is mere dogma until you realize the higher truth that form and function are one”. Furthermore, architecture would aim to fulfill conditions of organic unity. Organic display of proportions is an approach to animate a nonliving object. While most of the modernist architects tried to alienate their designs from existing urban and environmental patterns Frank Lloyd Wright was adamant on nature’s integration into design. Bruno Zevi (1950) in his work called “Towards An Organic Architecture” discusses on architecture organic like the concept of organic in nature, and that sustainable buildings are not intended to simply look organic and visually represent a harmony of nature and human habitation but also they must actually provide a functional harmony by participating in natural processes. As a reaction to pre-industrial historicist architecture, industrial period suffered the problem of predetermination in shape. At this time machine-like architecture was becoming more dominant and some architects like El Lissitzky started questioning this issue. Lissitzky, a constructivist, questioned Gestaltung meaning the process of forming where the "Machine" metaphor was questioned by other metaphors.

3.2 Analogies and Metaphors

Analogy meaning *proportion* in Greek is a cognitive process of transferring information and it is used as a concept that is in proportion with the subject. According to Braham (2013) the purpose of analogy is to acquaint us with new ideas by linking them to ideas we already understand. However, it is unconventional to analogously link new ideas with theories that are not generally understood in order to capture popular imagination. Metaphor a type of analogy, meaning *transform* in Greek. Antoniades (1992) addresses that metaphor is used for enlightening underrecognized through well-known subjects. It is a very common approach in interlinking two different subjects. According to Hausman (1989) analogy uses connections around already known concepts while metaphors attempt to discover new meanings. Metaphor and analogy in architecture are used for development of new languages. As a design language analogy and metaphor provide an access to architecture of blending in social and cultural phenomenon. Ungers (2011) argues how dissimilar entities can be compared through imaginative way. The comparison is mostly done through a creative leap that ties different objects together, producing a new entity in which the characteristics of both take part. For example Le Corbusier used mechanical analogies where in his book “Toward an Architecture” he states “Une maison est une machine-à-habiter” – meaning; a house is a machine for living in (Le Corbusier, 1923).

William J.J. Gordon examined the biographies of creative thinkers to reveal the process in which creative people actually solve problems. Based on collected data he concluded that the “*essence of any creative act involves trying to make something strange or unknown into something familiar or well-known or in trying to make something originally familiar or well-known into something new or strange”*(1961). Gordon developed four techniques for making the familiar strange and vice versa. First technique is based on Personal analogy in which the problem solver becomes an object and tries to feel, think, and act like that object. In the second technique which is called Direct analogy problem solver undertakes a comparison of parallel facts such as knowledge or technology. Gordon discovered that analogies based on biological science usually were more useful than other in which an example of Brunel solving the problem of underwater construction by watching a shipworm tunnel into a timber can be given. Third technique is about Symbolic analogy where problem solver gives a compact description of the problem. Fourth technique involves Fantasy analogy in which the problem solver engages problem as a wish fulfillment.

Peter Collins in his work called “Changing Ideals in Modern Architecture” (1965) separates analogies into four categories; Biological analogy, Mechanical analogy, Gastronomic analogy and Linguistic analogy. In Biological analogy, Collins points out that when science of morphology emerged it also triggered the contradiction of “*form follows function*” and “*function follows form*”. Uncertainty occurred on whether morphology had to respond to structures who lived or structures which grew. A number of sources proposed that "*life was a form building form"*. Later, Spencer affirmed that growth of crystals and organisms was similar. This influenced Frank Lloyd Wright in his organic architecture studies on Crystal plan forms. As a result advent in science had triggered another level of imagination in architecture. This has led some architects to develop concepts of emulating biology through analogies in adaptation of newly found scientific discoveries.

Progress of architectural idea towards biological input began in abstract zoomorphic designs as engraved figures and forms. However it did not represented the overwhelming idea of modern architecture which forced itself into analogies. Under the influence Rudolf Steiner's anthroposophy movement, Organicism with Imre Makovecz as one of the representatives tried to translate biological compartments to technical functional elements. At the beginning of 20th century those shapes that were compared by biological analogy were made by newly developing concrete and steel. Architects and Engineers such as Oscar Neiymar, Gio Ponti and Pierre Luigi Nervi conducted experiments with shaping concrete. Structural bio-morphism was used by Eero Saarinen in TWA Flight Centre and Frederick John Kiesler's Endless House which emulated continuous skin of a human body. New universal architectural iconography interpreted organic "green buildings" into a morphology based architectural form above physical performance. However, the use of morphology was only possible by advances in structural engineering, computer modelling, automated production, and novel materials. Jencks suggests that the beginning of this movement can be witnessed in the "organi-tech" architecture of Frank Gehry, Santiago Calatrava, Greg Lynn and in the"cosmic" forms of Japanese architects such as Arata Isozaki (Wines, 1997).

Figure 3.2: Kiesler’s endless house (Url-6, 2012)

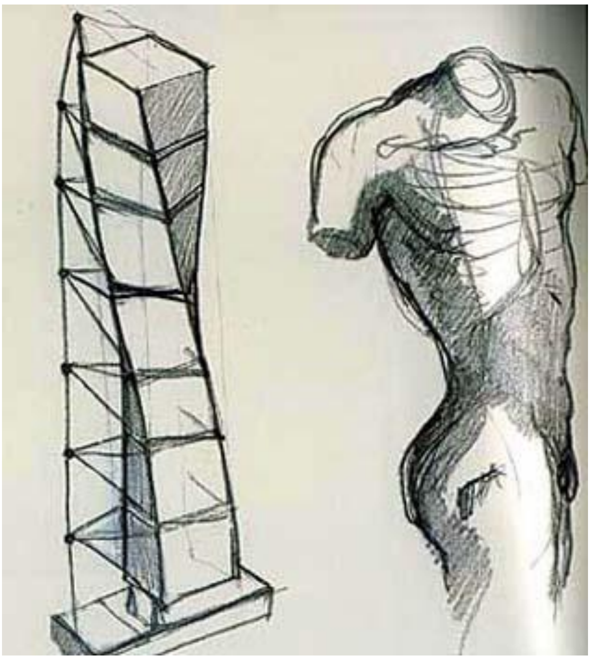

Figure 3.3: Turning torso by Calatrava used a metaphor of human body (Url-7, 2013)

Jencks relates metaphor with analogy as a design methodology. He defines that some architectural designs contain hidden metaphors. In his book “The Architecture of the Jumping Universe” Jencks (1995) explains metaphors under six different categories. Organi-tech where Architects continuing an obsession with technology and structural expression while at the same time taking into account environmental aspects, Fractals in which architect expresses self-similar, evolving forms, Computer blobs used within cyber space and its own grammar, Enigmatic signifier which is an inventive and “in desire of amazing” emergent metaphor without any ideology, Datascapes where computer models results based on assumption and Landforms used as methaphor for earth in large scales. These approaches underline architecture’s or architect’s point of views towards biology in which it shows tendencies and appreciation of natural systems without the necessary scientific foundation.

One of the major movements using biological analogies was Metabolism. Metabolic architecture taking its name from the Greek word *metabole* meaning a living organism with biochemical functions. The concept of ‘metabolism’ was affirmed at the international level at the Tokyo World Conference on Industrial Design held in 1960 by Kisho Kurokawa, Kiynori Kikutaka, Fumihiko Maki and Masato Otaka. They wanted to counteract aspects of modernism that adopted the approach of machine design in the context of architecture. Metabolic architects in theory thought that projects on large scales could have the potential to expand, grow resembling processes in nature.

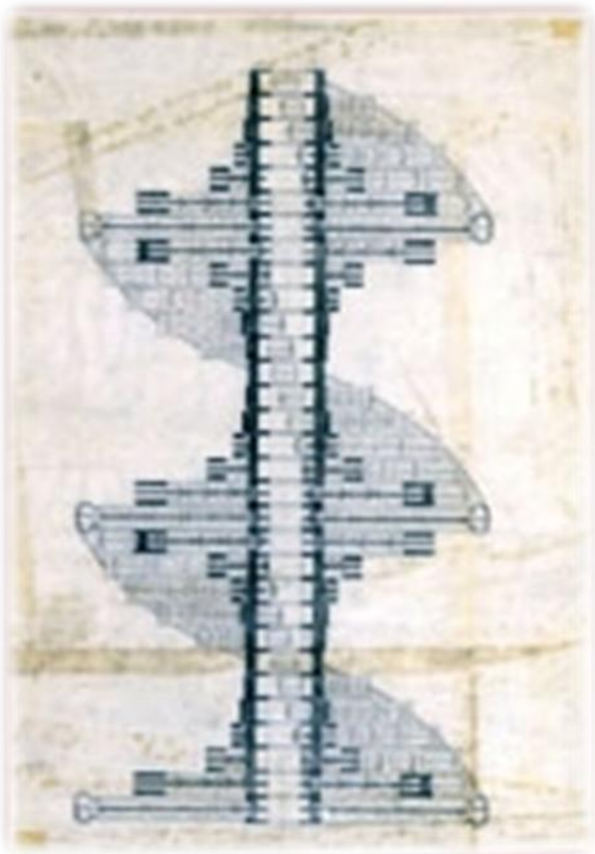

Figure 3.4: Helix city by Kurokawa (Url-8, 2013)

Some of the designs take utopian or virtual approaches while some others use biology as a metaphor. Nature is transformed into an instrument only existent through analogies. Analogy satisfies perception of the observer with a familiar product from nature. Analogy- a shortcut to “well-known subject”- becomes a toy of architecture as a safe perception. It is a shortcut to the "meaning" which is a delicate subject in architecture. Design as a primary solution or satisfaction of metaphor, application of a shape, a morphology of metaphor even with technical considerations procreates new problems. Steadman (1979) states that the trouble with biological analogy in architecture is that much of it has been of a “superficial picture-book sort, ‘artistic’ photos of the wonders of nature through a microscope, juxtaposed with buildings or the products of industrial design”. The expectation of organic growth as a morphological change in architecture, collides with the idea of biological behavior.

In conclusion this part has investigated the relation of architectural approaches which have tried to alter analogical understanding of architecture from machine like to biological one. Through the investigation it is assumed that this relation has been correlated with scientific and technological advancement of industrial modernization, hence in that context scientific implementations have merely achieved a visual success and caused a deviation of analogy in transfer of information into the architectural design.

3.3 Act of Building and Environmental Implications

Ecology is the branch of biological science that studies the distribution and abundance of living organisms, as well as the interactions between organisms and their environment. It encompasses the complex physical, chemical and biological surroundings that make up the habitat of an organism at any given time. Changing technology and energy means starting from mid nineteenth century with overpopulation, rapid industrialization and rise of production rate brought pollution and waste that could not be easily dissolved in ecology. Globalization and integration of societies who used to live in rural conditions brought new issues and therefore policies and regulations to be considered. High level usage of fossil fuels starting from late nineteenth century has established a certain standard in consumption that led to a never seen before pollution and production rate in which enormous amounts of waste have been produced.

There have been several major environmental issues such as global warming with unnaturally increasing temperature, pollution due to burning of fossil fuels, ozone depletion and shortage in clean water access, quick consumption of resources, deforestation and degradation of soil due to urbanization. While geographically sources aren't situated homogenously, in some territories countries suffer scarcity of fresh water while others use it as a trading asset. Modern communities unconcerned by agriculture due to industrialization populated urban areas. Cities as focal points of the rising population globally burden most of built area.

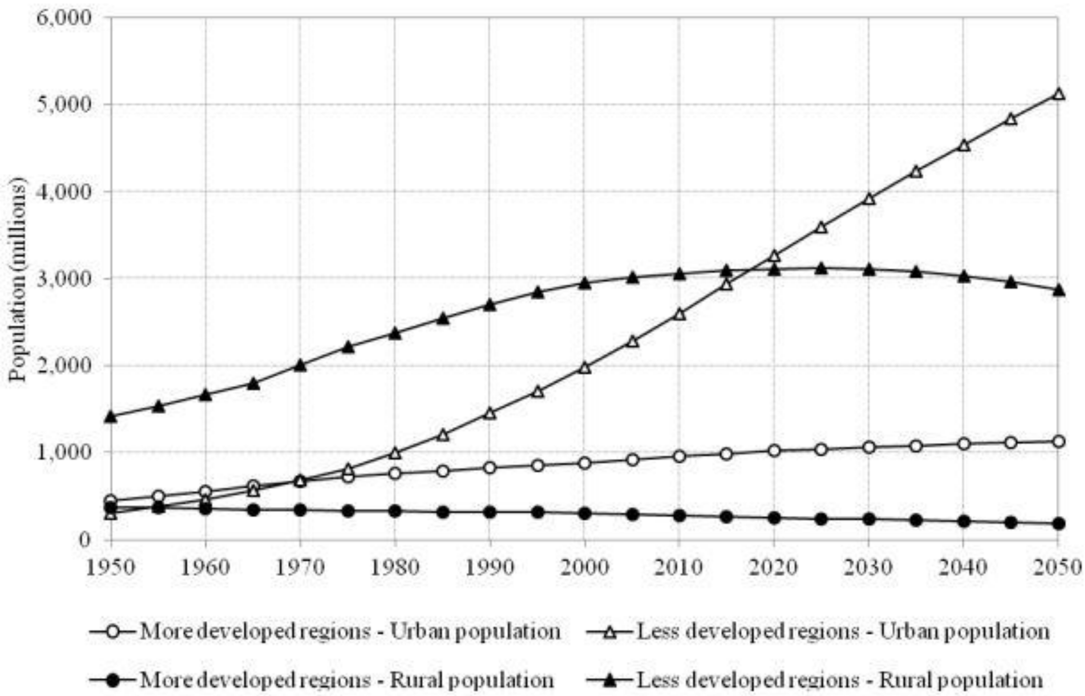

Figure 3.5: Urban and rural populations by development group, 1950-2050 (Gruber, 2011)

Although there is an increasing consumption of materials and energy, a large number of countries do not possess equal privileges. According to Worldwatch (2003) there is an immense inequality between developed and developing countries: developed countries, on the whole, enjoy provision for health, employment, education and an average gross national product hundreds of times greater than that of some developing countries, while elsewhere in the world over one billion people lack access to clean water and over two billion lack adequate sanitation.

Table 3.1: Global resources and environmental pollution, estimated share of the building industry (AD, 2001)

Global Resources		**Global Pollution**	
Resources	Building Use	Pollution	Building related
Energy	50%	Air quality	24%
Water	42%	Global Warming gases	50%
Material	50%	Drinking water pollution	40%
Land Loss	48%	Landfill waste	20%
Coral reef destruction	50%	CFCs-HCFCs	50%

Considering also the electricity required for the functioning of mechanical systems and services, the total increase of direct and indirect emissions from the construction sector is 75% higher than direct emissions alone (IPCC, 2007). Since Ernst Haeckel coined term “Ecology” in 1866 there have been serious remarks on how nature is being utilized. One of the first notices was in 1901 when John Muir reacted to massive deforestation. In 1962 Rachel Carson argued on controversial pesticides used in agriculture. Many organizations flourished due to underutilization and mismanagement of environment such as Club of Rome (1968), Friends of the Earth (1969) and Greenpeace (1971). United Nations began organizing conventions around the world for increased environmental awareness and use of resources.

> It is materially impossible for us to destroy the planet Earth, that the worst we can do is to engage in material transformations of our environment so as to make life less rather than more comfortable for our own species, while recognizing that what we do also does have ramifications (both positive and negative) for other living species (Harvey, 1998).

The most substantial attempt on environmental awareness began with Brundtland Report in 1987 followed by Montreal Protocol. Intergovernmental Panel on Climate Change (IPCC) 1988 and UN Conference on Environment and Development in Rio 1992 led up to 1995 Berlin Mandate which was the first UNFCCC conference of Parties addressing concerns about countries' capabilities in management of changing climate as the first international agreement. In 1997 Kyoto protocol was accepted by 189 countries including Russia in 2005. UNPCCC's objective is reduction of six greenhouse gasses which are; Carbon dioxide (CO2), Methane (CH4), Nitrous oxide (N2O), Hydro fluorocarbon (HFC), Perfluorocarbons (PFC), Sulfur hexafluoride (SF6).In United States Executive Order 13134 was issued in 1999 with the idea of: “Developing and Promoting Bio-based Products and Energy.” Its intent is to “stimulate the creation and early adoption of technologies needed to make bio-based products and bioenergy cost-competitive in large national and international markets” (1999).

Sustainability as a concept came into prominence with Brundtland Report in 1987. Sustainable development according to Brundtland Report asserts “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Union of International Architects embraced sustainability in World Congress of Architects Meeting in Chicago in 1993. Gruber (2011) asserts that the ecological and sustainable design movement began after the energy crisis in the 1970s. All kinds of efforts to reduce energy and resource input and processing in buildings have been experimented. On the other hand, when one parameter is considered highly important in architecture, the other aspects necessarily suffer: the aesthetic side of ecological design has for a long time been neglected. Designs such as first low energy and passive houses did not become famous for beauty in public opinion. The degree of pollution worldwide countenances the usage of more -familiar to nature- processes despite established network of conventional petroleum based processes. Ordinarily, utilization of nature and changing perception on it, is becoming a standard procedure. Matos and Wagner (1998) state that bio-based materials were used extensively in preindustrial societies, but have been replaced largely by materials manufactured from petroleum and other non-renewable resources since the early 1800s. On material level architecture requires a remarkable amount of energy and construction material and it is crucial to define the limits of necessities to be fulfilled without going beyond sustainability. Calkins (2009) explains how there has been a shift away from localized use of materials to centralized large-scale production and global distribution and that the usage of highly processed materials has increased against minimally processed materials.

According to Yeang (1999) ecological aspects have to be taken into account for the selection of materials in addition to constructive, aesthetic and economic aspects. Gruber (2011) emphasizes that all natural constructions and processes are optimized for energy use, and from this point of view all the following design principles of nature have to be conceived: Integrated instead of additive construction, optimization of the whole instead of maximizing single elements, multi-functionality instead of mono-functionality, fine adjustment with regard to the environment, direct or indirect use of solar energy, temporary limitation instead of useless durability, complete recycling instead of waste accumulation Integration instead of linearity, development by trial and error.

It is very critical to understand that the materials and their embodied energy comes directly from nature. Materials are refined, packed and distributed worldwide. There is a low amount of transition to more environmentally friendly minded materials. Specific materials and systems that already exist in the nature do not require adaptation to specific environments and therefore do not cost any waste and unnecessary procedures. These materials as of their production use *bio* as a forename. One of the common features in these materials is biodegradability.

Biodegradable type of materials appear to be under consideration of usage, however, Singh (2003) states that materials such as bio-plastics currently are not economically competitive enough with petroleum-derived ones because of the high costs associated with developing this market while well-established petroleum-based product development and distribution exists. Fitch (1990) points out that "until the advent of modern industrial production, with its vastly increased capacity at seemingly no physical cost to ourselves, the effort of making anything was too great to waste". Every object was therefore used, reused and adapted until it wore out, and even then, the parts were recycled.

3.4 Chapter Evaluation

This part has focused on unveiling architecture's developmental process since it was introduced to mechanical systems. It has presented two separate views on nature. First one being non-mechanical, it has incorporated environment as a basis for support of human life while the other view uses nature to a lesser extent where it undermines the functional properties of it by interpreting and exploring new meanings through nonfunctional analogies. Ecology encompasses the complex physical, chemical and biological surroundings that make up the habitat of every organism. Second view has triggered an act of contradiction between nature and architecture. Analogies used without functional parameters have averted biological necessities of the complex environmental properties resulting in environmental deterioration.

4. OPERATION OF BIOMIMETICS IN ARCHITECTURE

This part of the thesis will present a number of examples in relation with architectural design. Insight from these examples will underline some core principles of design process incorporated with the information provided by biomimetics research methods. Selection of the examples is based on diversify of biomimetics throughout historical development and it shows a drop in scales of treatment of the subject from large tensile structures to microstructures that are studied by polymer sciences in order to achieve an artificial biology. Throughout the evolution, complexity and diversity of systems developed as responses to environmental pressures and instabilities. Organisms that have excess capacities or redundancy survive environmental instability; those that are too completely matched to an environment – the efficient design – do not survive if the environment develops instabilities (Weinstock, 2006).

According to Cohen (2006) there are two ways in which one can utilize the lesson learned from living nature. First method is to produce original size features in order to achieve the performance observed in nature. Second method is to define suitable sizes for other features to modulate chosen conditions over required ranges. Biological processes and materials, down to the molecular scale, have to be understood for their advanced functionality and performance capacity of biological organisms. One of the most distinguishing characteristics of biomimetic mechanism is the ability to operate autonomously in complex environments by being multifunctional in order to adapt to random changes. According to Rao (2003) using multifunctional materials and structures allows nature to maximize the use of the available resources at minimum mass.

4.1 Structures

Beings in nature structurally encounter various forces such as contortion, buckling, compression and tractive force and manage to stay cool or hot through drastic climatic changes. It is almost impossible to separate structure from body or envelope while naturally occurring shape is based on the forces it is being exposed to. Several studies based on structure were done on architectural projects which had to fulfill the task of load bearing. Structures in this part change in scale from metric to micro and eventually to molecular levels.

One of the most well-known practitioners of natural structures was Frei Otto. In late 1960's, Frei Otto began multidisciplinary studies with Institute for Lightweight Structures in Stuttgart implicating principles of biology into his works. Otto (1988) studied *Gestalterdung* meaning emergence of form. For *Gestaltwerdung* morphological study is the study of structural efficiency which can be stronger but use less material. *Selbstbildung* or self-forming emphasizes the formation of materials to find their own forms by natural means. He used membranes and tensile structures which resulted remarkably similar to spider nets in working principle.

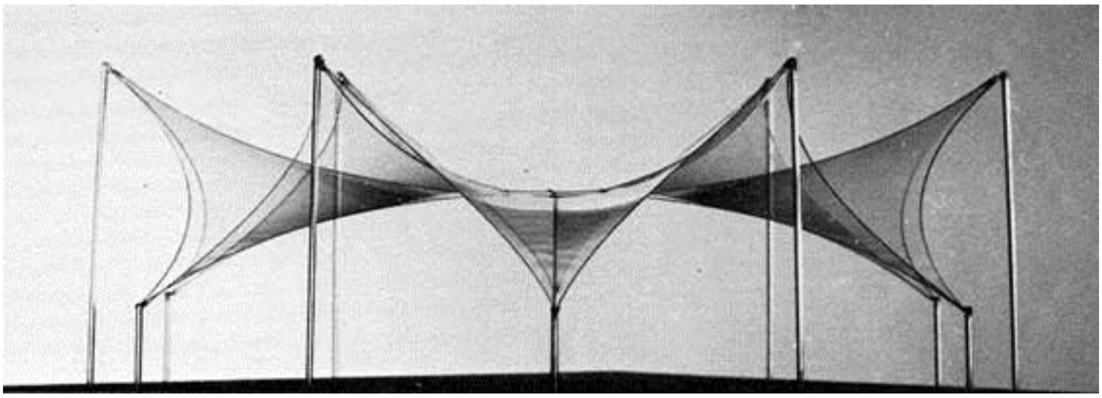

Figure 4.1: A model of tensile structure by Frei Otto (Url-9, 2012)

Otto's projects would involve tents with minimal surface areas based on stabilization by inversion of traction lines inside grid shells and pneumatic envelops whose form is determined by pressure ratios. Simple materials, lightness, flexibility, removable and changeable building method emphasizes inconsistency or an ephemeral approach. However, lightness means less material and less effort to produce it. Method of folding light material and rigidification of soft provided resistance. Otto's concern was on low energy structures made of soap films spreading between fixed points in order to cover minimal area (Otto, 1998).

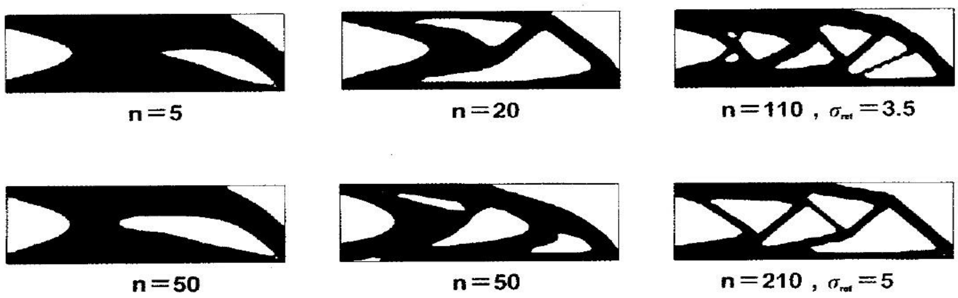

Figure 4.2: Material reduction by softkill option (Mattheck, 2007)

Contrary to Otto's approach, in recent events material is studied under the terms of redundancy and lightness by Computer Aided Optimization. Simulations that are made can be tested without the manufacturing of actual object. Finite element analysis is a numerical analysis technique that is used for obtaining solutions to the differential equations which define physical problems. "Softkill" suggests reduction of unnecessary structure as much as possible and optimizes topology of constructive parts while minimizing the amount of material (Mattheck, 2007). Topostruct uses similar principles for material reductions. Under generative computational process replicating natural processes it is possible to develop close examples of artificial structures. Simulating growth processes with system-extrinsic and system-intrinsic organizational information has potential in architectural design in terms of structure, process and material.

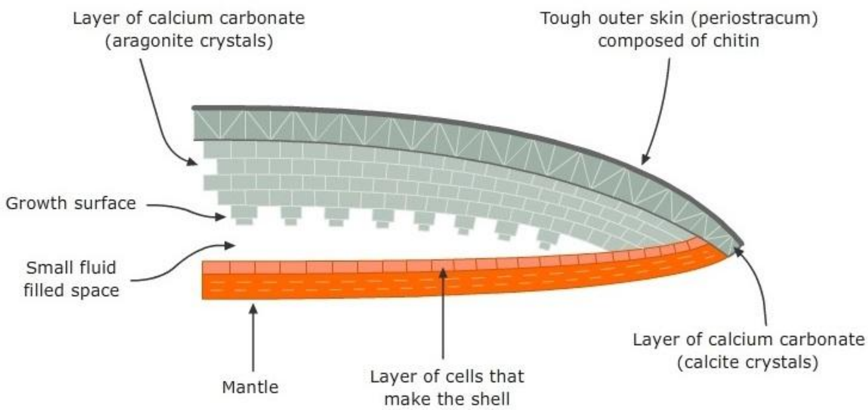

Figure 4.3: Structure of a typical mollusk shell (University of Waikato) (Url-10, 2013)

Perhaps the most meaningful example is Mollusk. Shells of mollusks are formed by proteinaceous matrix of calcium carbonate and ceramic phases. Constituent weak compounds turn brittle material into strong composites in order to protect soft creature inside.

4.2 Process

Species develop unique set of skills to survive through various conditions. As Nachtigall points out organisms have constant energy crisis and they are in constant motion of either preserving it or finding new resources to satisfy this very fundamental necessity. Energy has a differentiating meaning depending on the conditions. Some species live as a group such as *Mound Building Termites* sharing a common goal and space that maintains air temperature by building extensive system of tunnels and galleries in order to ventilate underground living space while others like *Stenocara Beetle* live a solitary life in desert seeking moisture from the air. Both of these examples describe peculiar processes. An example that is very often used in architecture is Eastgate Centre in Harare, Zimbabwe. Mick Pearce, the architect of the project based his design on principles of mound building termites. Pearce described what was demanded of the project;

> They said that no direct sunlight must fall on the external walls at all and the north façade (direction of summer sun) window-to-wall area must not exceed 25%. They asked for a balance between artificial and external light to minimize energy consumption and heat gain. They said all windows must be sealed because of noise pollution and unpredictable wind pressures and temperatures, relying on ducted ventilation. Above all, windows must be light filters, controlling glare, noise and security. (Atkinson, 1995)

The Eastgate Centre of Harare design structurally replicated self-regulating mechanism of mounds which provided consistent temperature without the support of air-conditioning or central heating. In order to achieve this constant temperature there are breeze-catchers at the core of the structure which draw in air, then cool it by pulling it through chambers carved out of the wet mud at the base, while hot air escapes through flues at the top of the mound (Tzonis, 2001). Energy and expenditure requirements dropped significantly when compared to similar sized buildings.

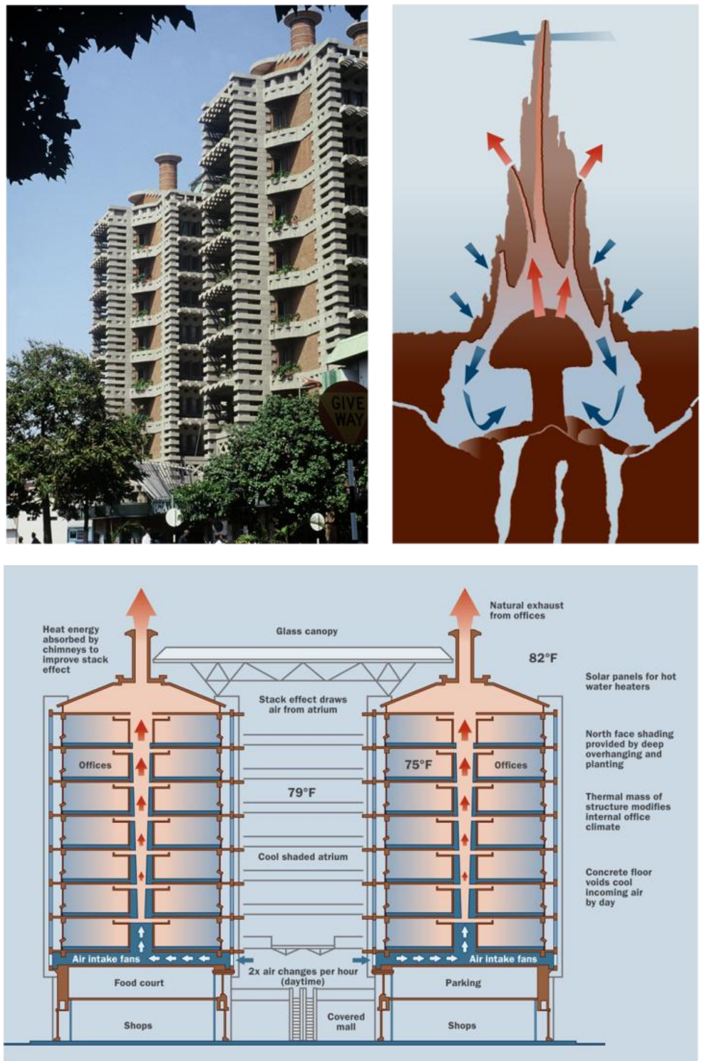

Figure 4.4: Eastgate Centre (Url-11, 2014)

Another example on processing of information is based on stand-alone organism. Professor of biology Andrew Parker studied the beetle from Namibian desert called *Stenocara Gracilipes*. Its body surface is covered with dissimilar convexo-concave surfaces including hydrophobic micrometer sized bumps and hydrophobic patches in between that are one-tenth the size of the bumps (Shinomura, 2010). Stenocara beetle lives in deserts close to seaside. It harvests smaller than usual dewdrops through moisture contained in the air. It is able to capture moisture from the swift moving fog that moves over the desert by tilting its body into the wind (Parker and Lawrence, 2001). Beetle stands up straight and waits until droplets pile up on its surface.

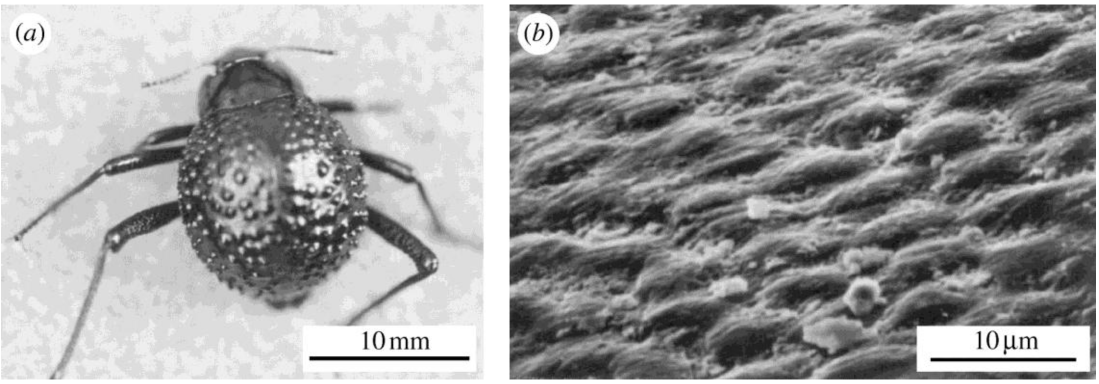

Figure 4.5: Stenocara gracilipes (Namibian beetle) (left) and micrometer sized bumps on its surface (Right) (Url-12, 2013)

Water-gathering material that mimics the skin of Stenocara has been developed by researchers from Massachusetts Institute of Technology. Layer-by-Layer method was used in forming of hydrophilic bumps on a solid bottom layer while area in between was covered by water-repellent fluoride compounds (Shinomura, 2010). On a larger scale dew collection method extracted from Stenocara Beetle can be used for securing water resources in dry lands. Application from this information was used in Sahara Forest Project. Moisture from seawater trapped by evaporator grills in the air is condensed and used for non-fertile land. Matthew Parkes proposed similar process of biomimicry for an arid region of Namibia with fog-catcher design using special polymer surfaces for the Hydrological Center of the University of Namibia (Killeen, 2002).

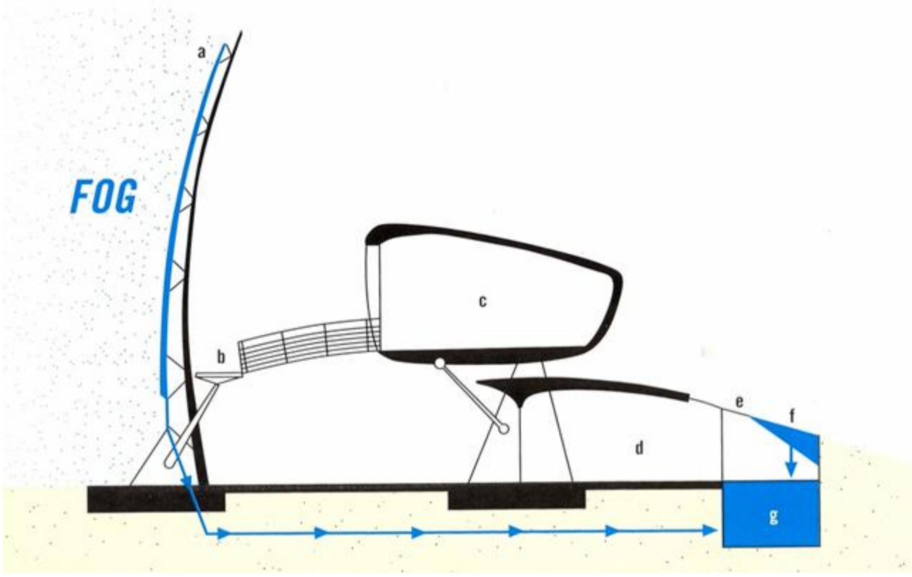

Figure 4.6: Hydrological Center of the University of Namibia adopted from Matthew Parkes (Url-13, 2013)

4.3 Materials

Materials produced by the information of biomimetics on micro and nano-scales are exceedingly important from architectural point of view due to features such as resistance and durability while being light and smart. Research and development methods are complex due to the scale it corresponds Water repellent surfaces, adhesives without chemicals, photonic materials all together contribute substantially to the quality and performance of built environment. Materials are developed mostly as Nanostructures. Biology also comprises of nanostructures. Recent developments in nano and micro-fabrication, as well as self-assembly techniques, are driving the development of new functional materials and unique coatings that mimic biomaterials (Cohen, 2006).

One of the most famous examples was based on lotus leaf. Professor Wilhelm Barthlott (1997) from Bonn University examined lotus leaves and discovered that microstructure and secretion of compounds on the surface have a synergetic effect that produces super-hydrophobic, self-cleaning property which has been called “Lotus Effect”. Surface has high adsorption power which can hold water upside down. Wettability of a solid surface by water is governed by material’s hydrophilic and hydrophobic property (Shimomura, 2010). Low level of surface free energy vests cleaning effect. Material that can be applied as a paint or coating with these properties is effective against hazardous gases and liquids.

Another example to micro scaled materials are antireflective surfaces which have been discovered several times on insect eyes (Stoddart, 2006) and leaves of plants in the tropical forests (Lee, 1986).Manufacturing of such material improves absorption of light. Vukusic (2010) explains that in certain animal and plant species, photonic-based colored appearances are very highly evolved while visual appearances of many animal species concurrently comprise optical features that are visible to human vision and those that are covertly concealed beyond human visual sensitivity. Shinomura (2010) states that the body color of jewel beetles with characteristic metal luster is called structural color which does not fade because the microstructure is shorter than the wavelength of light.

Figure 4.7: Jewel beetle (Url-14, 2014)

(a) (b)

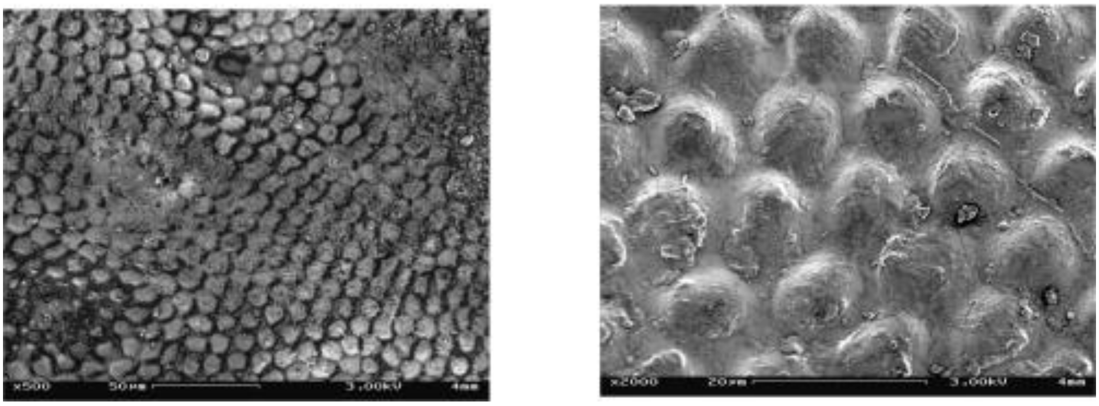

Figure 4.8: SEM (scanning electron microscope) images of jewel beetle tissue (Url-15, 2014)

Geckos’ setae is also mimicked in order to acquire adhesion properties in materials. These setae, which are microscopic hairs on the bottom of their feet, use van der Waals forces to run fast on smooth surfaces such as glass (Autumn and Peattie, 2003). This type of adhesion could provide alternative to chemically enhanced adhesives.

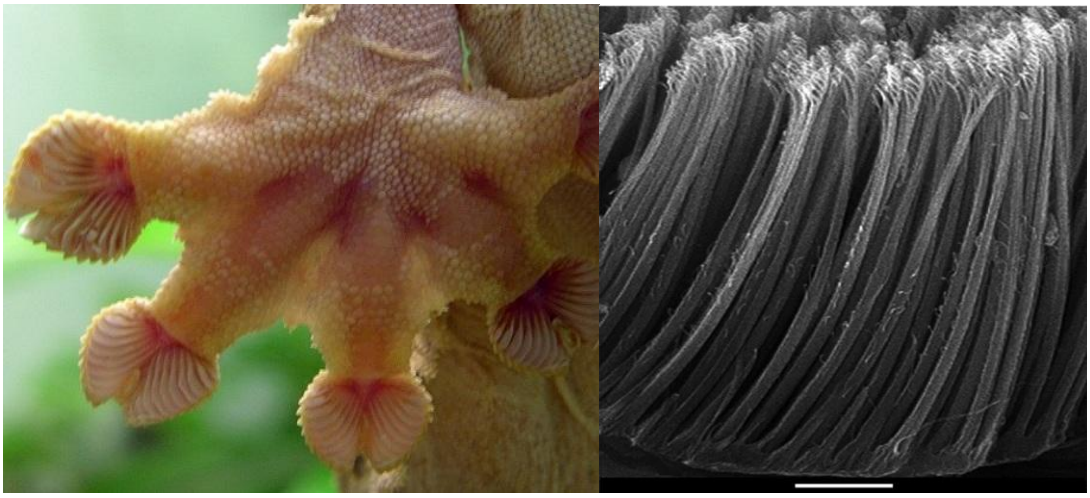

Figure 4.9: SEM (scanning electron microscope) images of gecko's setae (right) and gecko's foot (Left) (Url-16, 2014)

Most of the materials are in phase of development such as Shrilk discovered by researchers in Harvard's Wyss Institute for Biologically Inspired Engineering (2012). Inspired by insect's flexible and thin outer shell (cuticle) it is a combination of shrimp shells and protein of silk. It is claimed to be clean and lighter than but as strong as aluminum. Basic ingredients for Shrilk are fibroin and chitosan of which both are biodegradable and biocompatible.

Table 4.1: Summary of material's properties

Material	**Property**	**Scale**
Shrilk	Light Structure	Molecular
Lotusan	Self-Cleaning	Micro
Antireflective	Light Absorption	Nano
Gecko's Setae	Adhesive	Nano
Micro-structured Body Color	Fadeless	Micro

4.4 Chapter Evaluation

This chapter conveys an understanding about the mechanics of biomimetics through various approaches and examples. Selection of categories is outlined under three entities that could be used as design parameters. Entity of structure represents a solid base of total object responding to physical forces. Chain of events -such as adaptation- can be described as a “process” where it is constantly seen in natural cycles. Material level is perhaps the most crucial step because it determines capabilities/properties or skills which are fundamental for adaptation. Characteristics of examples indicate a complex system that is in need of accessible and substantial technical foundation in order to be easily applied into architectural design. Most of the examples constitute common principles. Main points of sources of biomimetics used in examples and approaches demonstrate following general principles:

- Reduction of Weight and Material
- Usage of Simple and Local Resources
- Lowering Energy Demand of Production and Maintenance
- Utilization of Materials on Micro Level
- Multi-purpose Oriented
- Biodegradable

Most importantly the understanding of biomimetic architecture delivers crucial information for the discussion on form finding. Concept of form obtains a new scale because biomimetics as a discipline is predominant in material sciences and therefore most of the recent cases are based on micro scales. Although some examples are not up-to-date all of them outline the basic principles of biomimetics in order to help architecture understand and prevent it from misusing analogies that are employed for the purposes of collecting information. Examples display that architecture is not on par with other engineering disciplines. Information gained through biomimetic approaches should be used as an input in the early phases of architectural design in order to achieve sufficient effect overall and reinstate a level of contact with process of environment.

5. DISCUSSION AND CONCLUSION

> It was nothing but the logic of illusion. It was a sophistic art of giving to one's ignorance, indeed even to one's intentional tricks, the outward appearance of truth, by imitating the thorough, accurate method which logic always requires, and by using its topic as a cloak for every empty assertion (Kant, 1781).

Architecture for a long time has incorporated environment as a basis for support of human life. Formation of something as contradictory as decline of environmental well-being demonstrates how the nature as domain has been neglected as a database of problem solving information and systems. Now, with the biomimetics it is urged to save itself once again. However, crucially its characteristic consists of several layers of disciplines and therefore something as complex as this is not instantly suitable for a problem solving architectural design.

It is revealed in the previous chapters that beings in nature possess patterns of production techniques and system design contrary to those that have been cultivated by human since the industrial revolution. Biology has been observed as a constant formation of adaptations and solutions for the need of survival. Since late modern period, -equipped with newly available production methods - architecture focused on formation from structural point of view. This attitude was forged mostly by the aspects such as newly available, highly strong materials which would grant unusual forms. Form is a major component in nature however architectural form has a bit different meaning than the one in nature.

The essential difference between biology and engineering comes from their very nature. Organisms composed within biology evolve through natural selection where they constantly adapt and develop new set of skills. The versatility taking place in this process is measurable by classification of descriptions. In contrast, engineering has certain mathematical rules that provide prescriptions in order to deliver functionality. Methods such as TRIZ are useful in transferring mechanical and functional features from one field to another by defining problems and responding through classification of several solutions based on comparison of large variety of solutions. Furthermore, both biology and engineering are driven by the purpose of resolution of certain problems and that is where they intersect with each other. Architecture, on the other hand, is bound to use engineering as an interpretation tool for the reasons of correct conduct on environmental aspects. Biology, therefore is to become more technically comprehensible for architects and other fields.

Transfer of knowledge between disciplines is very complex but an important phase for design studies. Design without accurate information is reduced. This does not imply a negation towards analogies but rather states that the architect's observation might be inefficient when the observed is a foreign discipline.

Mimicking of biological systems with a direct analogy has to be one on one while there is also a possibility of where indirect analogy uses the biological system as inspirational analogy without mimicking every aspect. Analogies based on strategies, rather than those based on descriptions of phenomena emphasizing forms are to be expected to lead a suitable design. In contrast Vogel (2000) argues that analogies between fields cannot deliver information. This attempt to correlate elements of different categories could result in further misconstruction. In some cases imitation of phenomenology is not possible if the conditions aren't equal. The essence of imitation is that it responds to specific situation by a specific solution. Vogel's (2000) study called "Cats' Paws and Catapults" refers to analogies of biomimetics as "*naive Biomimicry"* because scientists used exact same technology found in nature without adjustments and implemented it on human scale designs where the results were unsuccessful. Vogel expresses an understanding from the past where it was not as possible to analyze whole biological system as it is now. However, biomimetics is improving further in development of research capabilities and analysis and therefore biological phenomenon will eventually become a scientific and direct analogy.

Perhaps, architects look for the end result of such processes and impose those images onto buildings. One of the main concerns with biomimetics in architecture is the encapsulation of the phenomenology by imitation on to an object which would undermine biological capabilities by this reductionist approach. Biology applied to architecture does not dictate a geometry or aesthetical specification but a process of efficient necessities. It does not require any aesthetical obligation but architects tend to exploit the angle of aesthetical elements through metaphor -as a language that is foreign to biology- for the morphological use.

New understanding on biomorphism must depend on meaning that derives not from specific representation but from a more general allusion to biological processes. While it is being used as an artistic merit, biological input in architectural design is neglected in manifestation of environmental awareness and it could be argued as a defect in architecture's progress in modern history. Biomimetics, -although deriving from biology- has no obligation to be ecological or ethical. It is an altering system to those that are in use at present. If the biomimetics was to be presented as single purposed, such as just efficiency, the development of the field in architecture would be limited and possibly exploited as "green-wash" through misrepresentation. Even more obstacles would arise for its integration to architecture when the subject of interest is not thoroughly analyzed.

On the other hand, computer generated form finding and emergence is a crucial part of biomimetics, however, crucial distinction is that it does not use generative tools as in digital morphogenesis. For that reason, the deployment of information into the virtual world with the idea of growth and change is lost when transferred into real world. As in morphogenetic design, scientific theories are operated through a computerized mathematical language within its own nature. For example, nonlinear systems are more of a mathematical theory adapted into grammar of a shape with different obligations. It is possible to use a direct theory or system extracted and interpreted from the nature as a digital script in the design phase. Vincent (2006) gives an example on a computer model that can describe the behavior of ants or termites where the goal has been set by the experimenter. However, in real life, the goal is set implicitly by the individual organism and the function of a biological system is the action needed to achieve a useful or desired condition.

Architecture is non-living, however it is part of inanimate nature, and is subjected to the same physical principles and processes and for that reason resemblance is as significant as analogous functions. Forms of organisms are determined through the interaction of both organic and inorganic environments. This interaction according to Gruber (2011) disregards approaches to morphological translations.

Concerned with the lack of architecture’s information on process in nature, Salingaros, a mathematician argued on Jencks’ perception of modern architecture. He assumed that there is a basic confusion in contemporary architectural discourse between processes, and final appearances which neglect propositions of scientific studies on complex forms and processes of adaptation and self-organization. Architecture consistently seeks to be new and with this attitude- on a long run – distorts its own theoretical basis. Another possible aspect to newly forming styles may be that working with existing knowledge could be considered a top down approach contrary to producing new information. Form finding analogies work with self-organization based on information. Gaudi used gravity while Otto examined the principles of tension in minimum energy surfaces. However, biology was also used incompetently as a structural logic out of principles of physical force. Significant duality exist within biological system for the compensation of produced in order to be reusable such as carbon based oxygen production, systems balancing and canceling each other in general. Biology offers a great model for the development of mechanical tools, computational algorithms, effective materials, as well as novel mechanisms and information technology. Hierarchy is exceedingly important in the solution of problems; this is not obvious because current technologies are either not significantly hierarchical, or ignore any hierarchical structure. However, a strictly scalar approach is difficult since many basic biological functions occur in organisms over a very wide range of sizes. It is questionable that design capabilities, materials, manufacturing and construction methods of modern man differ from methods in nature therefore it is not possible to literally translate the efficiency. Biology as a discipline can be applied to engineering’s manipulation of system but biology, as mentioned earlier, is a descriptive science, therefore not interchangeable as a conceptualized design.

Although biomimicry may hold answers to future architectural problems, as of now it appears that its application to architecture is still premature. However, it could prove useful in being applied to isolated singular functions on smaller scales. To create a truly functional architectural biomimetic model for a society, the design would not only have to mimic specific traits or systems found in nature, but the overarching systems as well. Biomimetic architecture should imitate ecosystems and then the minor systems working in unity within them. It is obliged to be completely integrated.

As biology is the science of life, paradigm for architectural design on biology has to past shallow biological metaphors or superficial biomorphic approaches. A fully biological architecture is currently not fully plausible within the technological possibilities, however, it is undoubted that architecture interacts with the rest of the environment and its complex biological systems. It is than an absolute necessary for architecture to get involved into multi-disciplinary field of biomimetics.

It is possibly a common mistake that the architect redefines and conceptualizes nature as an abstract idea for it to be a purpose of design. Analogical approaches perhaps misused underdeveloped biological input which caused deviation in conception of biology. In terms of environmentally suitable design biological knowledge of an architect has been limited to imagination and metaphors so that it could become a geometrical application. Now, however, it is certainly a case in which biomimetics should provide depth into architectural thinking. In order to approach nature in terms of engineering from a designer's point of view, it is necessary to sort biological capabilities along technological categorization using a top-down structuring or vice versa. Gaining the most from nature's inventions requires bridging of the gap between the fields of biology and engineering. The field of biomimetics is multidisciplinary requiring the use of expertise from biology, engineering, computational and material sciences, robotics, neuroscience, biomechanics, and many other related fields. As a field in-between it has to be adaptive, however, for it to be a part of architecture, following issues have to be resolved;

1. Lacking standard technical basis in biomimetics for a progressive architectural design due to difficulty in transfer of information as a functional analogy.
2. Historical progress establishing a misleading non-scientific analogical interpretations
3. Research and Development limited to commercially interested industries
4. Complicated for architect as a design feature due to its deep and versatile multidisciplinary characteristics

Analogical approaches that do not feature scientifically correct biological ingredients have created problems particularly in terms of environmental adaptation. Architectural approaches that are scientific or epistemological will provide new and versatile qualities equal to the number of vast number of already existing systems in nature with the growth of information domain. One of the major issues which faces architecture is crossbreeding of fields from various sciences. As biology coalescences with other fields products are rapidly based on biological preferences due to environmental concerns. Architecture's duty should be to get acquainted with biological input not just on basic level but in detail. There is a vast territory to be explored for architecture in biology that could provide solutions concerning efficiency in every department.

Commercial exploitation of biomimetic studies is “bottom-up”, which is an inefficient procedure in terms of theoretical usefulness for other disciplines. The main difficulties in exploiting biomimetics arise from lack of awareness of biomimetics in academic and industrial fields. This study underlines that all the successful examples reach a level of conduct within a group of researchers that come from different backgrounds. It is recommended that studies taken on biomimetics should be implemented within the earlier stages of architectural education by integration of molecular biology and similar disciplines.

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CURRICULUM VITAE

Name Surname: Amar Pasic

Place and Date of Birth: Mostar, Bosnia and Herzegovina, 05.07.1988

E-Mail: amar.pasic@gmail.com

B.Sc.: Istanbul Technical University